XEROX

Xerox University Microfilms
Ann Arbor, Michigan 48106

WESTERN AMERICANA

Reproduced from the original in the collection of
THE UNIVERSITY OF ILLINOIS LIBRARIES

52d Congress, 1st Session. | SENATE. | Ex. Doc. 41, Part 2.

ARTESIAN AND UNDERFLOW INVESTIGATION.

FINAL REPORT

OF THE

CHIEF ENGINEER,

EDWIN S. NETTLETON, C. E.,

TO THE

SECRETARY OF AGRICULTURE,

WITH

ACCOMPANYING MAPS, PROFILES, DIAGRAMS,
AND ADDITIONAL PAPERS.

PART II.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1892.

TABLE OF CONTENTS.

Pages.

Letter of submittal 5
Introduction 7–9
The Pecos Valley; (*a*) Pecos Valley subterranean waters 11, 19
Underground water surveys; report of W. W. Follett, assistant engineer; (*a*) Cheyenne line; (*b*) Sterling line; (*c*) Frenchman line; (*d*) Big Springs line; (*e*) North Platte line; (*f*) Lexington line; (*g*) Loup line; (*h*) Grand Island line; (*i*) Garden City line; (*j*) Dodge City line; (*k*) Great Bend line 19–29
Norton, Kans., or the one-hundredth meridian line ....
Underflow and irrigation problems within Kansas and Nebraska 30–34
Movement of the underflow in river valleys 34–38
Raising water by mechanical means 38–40
Artesian wells—data of 40–74
Tabulation of artesian well data 74
Source of supply of the Dakota Artesian Basin. (*a*) Geological report from O. C. Mortson on section of Montana 78–83
Artesian well facts and theories 84–87
Red River (North Dakota) wells; (*a*) Follett's report on Red River Valley Artesian Basin 87–95
Artesian basin at Miles City, Mont 95–97
Yellowstone subterranean water and irrigation 97–100
Springs at the foot of the eastern slope of the Missouri coteaux 100
The Tiffany Underflow Basin. Report by Mr. Follett 100
Devils Lake and its connection with the Cheyenne River 100–103
The underflow from Turtle Mountains 103–105
St. Marys River, north Montana. Its diversion from Canadian territory 105–107
Climatic condition of the Great Plains 107–108
Artesian well irrigation and experimental work 108–113
Artesian wells data 113–115
Artesian legislation 115–117

TABLES AND ILLUSTRATIONS.

Tabulation of artesian wells data 74
Geological map of portion of Montana, showing imbibition of rocks 78

Appendices I to XXIII, being profiles and maps, and appendix XXV, in four parts, being record of wells examined on the various underflow lines, are placed at end of Part II. Appendix XXIV is included in tabulation of artesian wells data.

LETTER OF SUBMITTAL.

DEPARTMENT OF AGRICULTURE,
ARTESIAN AND UNDERFLOW INVESTIGATION,
Washington, D. C., December 24, 1891.

SIR: I have the honor to submit herewith the maps, profiles, and final report of the Chief Engineer, in compliance with the instructions of the Secretary, dated October 16, 1890.

Very respectfully,

E. S. NETTLETON,
Chief Engineer.

To SECRETARY OF AGRICULTURE.

INTRODUCTION.

ARTESIAN AND UNDERFLOW INVESTIGATION,
Washington, D. C., December 24, 1891.

SIR: In compliance with your letter of instructions, dated October 16, 1890, I left for the field of investigation on the 19th of the same month. As the time for making the investigation and report was then limited to the 30th day of June, 1891, it was considered advisable not to undertake any fieldwork in the northern portion of the country, as the season was so far advanced, but postpone it until spring. Active work was begun first in Nebraska and Kansas.

Maj. Fred. F. B. Coffin, then State engineer of South Dakota, who had been employed early in the season by the Department as agent to collect data concerning the artesian wells in the northern portion of South Dakota, was again employed as engineer to assist in the same line of inquiry. The work in the entire State was assigned to him. He was instructed to continue this inquiry so long as he could do so profitably. The inquiry was continued up to the 1st of January, mainly by means of correspondence.

Mr. W. W. Follett, formerly an engineer in the employ of the U. S. Geological Survey, was appointed assistant engineer November 1, and was immediately assigned to the work of making surveys of the Arkansas and Platte River Valley underflow waters, which was continued nearly to the close of December, when the weather became so bad as to prevent carrying on the field work any further, except in the South.

The month of January was spent in working up the notes and making maps and profiles and a progress report of the work performed up to this time. Before going south a trip was made to Wyoming to confer with the State engineer and others regarding the line of investigation to be made in that State early in the spring.

On January 31 Assistant Engineer Follett and myself left Denver for New Mexico and western Texas, mainly for the purpose of making an examination of the Lanoria mesa in Texas and the Pecos Valley in southeastern New Mexico. The month of February was spent in this work. Early in March I was advised that Congress had extended the time from July 1, 1891, to January 1, 1892, for completing the investigation and making the final reports.

This change necessitated a revision of the former plans, which had contemplated putting on a larger force, and to begin work in the Dakotas and Wyoming as early as the weather would admit in the spring. In view of the extension of time six months it was discovered that the allotment for the expenses of the engineering work would not admit of increasing the force thereof if the investigation was to be continued that long.

After a conference with the chief geologist regarding the amount and nature of the work to be done thereafter, it was thought best to so divide the work of the two branches as to distribute it as uniformly as was practicable to do over the whole section included in the terms of the act designating the area to be investigated. As the geologist had arranged to spend nearly the quota of the time naturally belonging to the different States in Texas, Nebraska, Kansas, Colorado, and Wyoming, I decided to shorten the time that I intended to devote in the engineering investigation in these States. This would give my division more time to work in the Dakotas, where there appeared to be a necessity for an investigation of an engineering character that required immediate attention.

In view of this arrangement Mr. Follett was instructed to improve the first opportunity of favorable weather to make an examination of the underground waters along the base of the foothills from Cheyenne to Laramie City, Wyo.

There appeared to be a necessity for making additional surveys of the underflow in the valley of the South Platte, the drainage valleys of the tributaries of the Republican River, and also across the valley of the Loup River these surveys were accordingly made, the latter at the request of the geologist.

Early in May active work was begun in the Dakotas, and was continued in these States and Montana until the last of September, when the fieldwork was practically closed. Maj. Coffin took up his work again on the 15th day of March, and continued until the 1st of July.

The engineering investigations have been carried on with two assistants, one constantly employed and the other five and a half months, and a rodman employed from time to time, amounting in all to about eleven weeks.

The time being so limited and covering so extensive a field of inquiry has entailed a great deal of labor in getting over so large an area, and has therefore greatly increased the percentage of time spent in traveling as compared with the net time for the work in hand. I find my own mileage has been 22,580 miles traveled by rail and 1,108 miles by wagon and on horseback. The distance traveled by Assistant Engineer Follett has been about the same number of miles, but with a larger percentage in wagon and on horseback.

I have found it necessary to make some changes in my progress report; also to add considerable matter to the final report of the same nature which is so connected with the progress report as to require repeating many portions of it. The profiles of the surveyed lines of the Arkansas and Platte valley underflow waters are again submitted. All the profiles of the former report have been redrawn and are now in proper form to be lithographed, with important data added previously omitted.

I have gone into considerable detail concerning the deep artesian wells in the Dakota artesian basin, and have included some of the most important ones that have been drilled within the past twelve months, in addition to several that were not noticed in the former report. I have also included many of those that were examined last year, but not fully reported on. The inquiry relating to the artesian wells has been made more comprehensive in the recent investigation than last year. We found at the beginning of the present inquiry that there had been several important changes in the flow and pressure of many of the wells that were examined a year ago, and to account for these changes we found it necessary to make particular inquiries regarding the flow to the surface. This information has been obtained, so far as possible, from the contractors or the parties who did the work. It is hoped that the detailed reports of this work will not be considered out of place. The questions concerning the relative depth of the different strata and veins of water, the seating of the casing in suitable rock, the methods used to make perfect joints between the strings of different sized casing, and the best methods of preventing clogging up of wells are very important matters in the future development of the artesian basin.

Probably no portion of the engineering investigation has been so productive of results that have been of so much immediate benefit to the country as those carried on in the Dakotas for directing and instructing the people in the proper methods of utilizing the water from their artesian wells. The little time and money spent in this line of work has, without doubt, been many times repaid by the value of the increased yield of the crops this season by aid of irrigation.

The statement is made by men who are in a position to know, that the encouragement the people of South Dakota have received during the past two seasons from the interest the General Government is taking in their behalf has been the means of increasing the acreage of wheat alone, the value of which exceeds many times the whole amount appropriated to carry on the artesian underflow investigation. Our own observations verify this statement.

I desire to acknowledge the many favors and valuable assistance rendered this branch of the investigation by the people upon whom we have had to depend largely for much of the data embraced in this report; also the valuable aid of my assistants and especially to W. W. Follett for his efficient services and untiring energy from the beginning to the close of the investigation.

ARTESIAN AND UNDERFLOW INVESTIGATION.

PECOS VALLEY.

The investigation of questions pertaining to subterranean waters has been the chief work of the engineering branch of the artesian and underflow investigation, and this report will be confined mainly to presenting and discussing such questions as are required by the first clause of the act under which this investigation is carried on.

To the former artesian well inquiry has been added that of investigating the underflow, which has greatly enlarged the scope of this work, and has made it necessary, in some instances, to travel over the same ground in our investigations, but where it has been practicable to do so we have avoided this in the engineering branch, and have taken new fields.

It was intended to make an examination of the Lenoria Mesa subterranean water supply, but I found that Mr. Hill, assistant geologist, had made a geological examination of it and the country around for the people of El Paso the year before, who were investigating the possibility of obtaining an artesian water supply for the city and water for the irrigation of the fine body of land on the above-named mesa. The result of his investigation will doubtless appear in the report of the geologist.

THE PECOS VALLEY SUBTERRANEAN WATERS.

The accompanying sketch map (Appendix No. 14) shows the location of the Pecos River and its tributaries in Chaves and Eddy counties, formerly the eastern portion of Lincoln County.

The Pecos River heads in a low range of mountains near Santa Fe. It affords little water for irrigation along its course until it is joined by the Rio Hondo, excepting in early spring and in the rainy season in the fall.

From Roswell to Black River, a distance of 100 miles, the Pecos River is reinforced by numerous and constantly-flowing springs, whose total volume is nearly 1,000 cubic feet per second.

Referring to the map, it will be observed that the drainage channels of the Pecos are on the west side of the stream.

Black River, Rio Penasco, and the Rio Hondo are the only tributaries that ordinarily carry water in sight into the main river.

The waters of the other tributaries usually sink before reaching the Pecos. The mountains in which the principal tributaries of the Pecos head are covered with timber, except the Guadaloupe. The Sierra Blanca Range is the highest, and is generally covered with snow from the middle of November until May or June. This range reaches an altitude of nearly 12,000 feet above sea level, the top of the highest peak being above timber line. The Capitan and Sacramentos are about 9,000 feet above sea level, and the Guadaloupe about 7,000. The waters flowing from the western slope of these mountains all sink soon after passing out of the foothills. There are evidences of an ancient river, with here and there remains of irrigation works on the west side of these mountains. This lost river seems to have at some time carried quite a volume of water. Its course was southerly through a valley lying between these mountains and the San Andreas Range 50 miles westward. There are no running surface streams in this valley, although there is considerable water flowing towards it. This valley extends south to the Rio Grande; the south end is near El Paso, and is called the Lanoria Mesa. Prof. Hill will present the facts and theories concerning the subterranean waters in this valley and mesa in his report.

The whole country between the Pecos River and the mountains to the west is underlaid with limestone; in fact the mountains themselves are in the main of limestone formation. Under the limestone lies a conglomerate composed of gravel and bowlders embedded in a matrix of lime and sand which closely resembles a coarse mortar or concrete. It is in this conglomerate the springs are found, sometimes at the contact with the limestone, but generally some distance below. The limestone strata of the country are mostly inclined to the east and toward the river, though in some localities they are turned up at such angles, as to present excellent opportunities for rapidly conducting water through subterranean passages to the conglomerate.

Black River, as it is called, is nothing but a storm-water channel into which four springs discharge. All the water from these springs would soon sink and be lost in the gravel and bowlder bed of the channel if it was not taken out by irrigation ditches. Three of these springs discharge 5 cubic feet per second each. Blue Spring, the lowest one down on the stream, has a discharge of 17 cubic feet per second. Three thousand acres are reported to be irrigated from this supply. The water of the Blue Spring comes out at the bottom of a ledge of conglomerate. The hills on each side are some 100 feet high, and are of the same formation. In my judgment the Black River springs are nothing but the reappearance of water that runs off the Guadaloupe Mountains, which sinks into the débris at the foot of the cañon and is carried along the conglomerate for many miles, where it again appears at the surface in springs of clear but very hard water.

The largest single spring we saw was in the vicinity of Roswell. Here are four springs which break out on the prairie, each of which has a small river of water running from it. The rivers formed by these springs are the North and South Spring rivers, and the North and South Berendos, all of which join the Rio Hondo just before it enters the Pecos. The spring forming the North Spring River is the largest of this group; its volume is about 105 cubic feet per second, measured 2 miles below its source. The water of all these springs comes from the conglomerate and is undoubtedly the reappearance of water that has found its way into the limestone formation that occupies the country to the west towards the Capitan Mountains.

The upper Rio Hondo is formed by two mountain streams, the Rio Ruidoso and Rio Bonito. There is considerable irrigation carried on on these streams and on the Hondo, a short distance below the junction. The amount of land that is irrigated from these streams seems to be adjusted to the volume of water at its minimum stage. The water in this part of the Hondo rapidly diminishes in volume as it leaves the mountains, until it is lost entirely before getting out of the foothills.

The melting snows in the mountains and sudden and heavy rainfall often sends quite a large amount of water through the whole length of the Hondo to the Pecos.

A reservoir company has been organized to build a series of storage reservoirs 12 miles above Roswell for the purpose of storing the early spring and storm waters. The plan of this company is to construct two dams across the valley of the Hondo at suitable places; one 50 feet, the other 80 feet in height. The holding capacity of these reservoirs is estimated to be 138,720 acre feet. The area covered by the proposed reservoirs is 5,594 acres. The cost of the whole work, including dams, wasteways, and 12 miles of canal, is estimated to be $232,630. In the valley below the reservoirs is a large body of fine land which it is proposed to reclaim; without water, is almost worthless.

The Rio Feliz is a stream that heads in the foothills and has considerable constantly running water in its upper part which comes from springs, but as is the case in all this part of the country where the channel is in limestone, it soon loses itself and does not appear again except in a few places, and then only in sufficient amount for stock purposes.

The last stream visited, the Rio Penasco, presents an interesting instance of what has been done, unintentionally in part, to prevent the water from sinking and losing itself in the soil and limestone of its channel. Here is a stream which heads in the timbered mountains of the Sacramentos, bringing down from them at all seasons of the year not less than 150 to 200 cubic feet of water per second, which formerly disappeared before it had hardly left the mountains. Along its channel in the foothills, and on the plains, water formerly only stood in pools, and no water, excepting flood and storm waters, apparently ever reached the Pecos. Now, it is a running stream its entire length, even after considerable of it has been used for irrigation. The cause of this is accounted for in two ways. One is by the result of a successful attempt to carry the water some 10 miles or more in a new channel, over a section where it formerly all disappeared, the other by the continual tramping of the bottom of the channel by thousands of cattle that go daily to the streams for water. I am informed that years ago during the summer time the Penasco would all sink just below the town of Upper Penasco. Some farmers owning land about 13 miles below the town, desiring to obtain water for summer irrigation, conceived the idea of making a new channel, and, where necessary, to improve the old one, hoping to get a sufficient amount of water down the channel for irrigation through the entire season. An attempt was made a year or so afterwards which proved successful, having not only enough to supply themselves but a surplus, which has been appropriated by others, and a lawsuit has come up in connection, and the courts have been applied to to settle the rights to the use and ownership of this surplus water. There seems to be good reasons for believing that the tramping of the earth and the gravel bed of the stream has packed and puddled it so as to prevent loss by infiltration. Within the past few years large numbers of cattle have found their way into the Penasco country. It is estimated that 12,000 to 15,000 head of cattle go daily to the Penasco for water. In warm weather these cattle go into the stream and stand there for hours tramping about. The volume of water has increased so much in the lower Penasco that within the last two years a number of settlers have located there, and have taken up several thousand acres of land, and are now building irrigation canals.

Besides the springs that we visited, there are hundreds of others scattered over the country; to examine and make note of them all would require more time than was at our disposal.

The flow of the Pecos River at Eddy is 1,000 cubic feet per second of spring water; the greater part of this comes into the river below its surface, and the springs are not discernible on that account. The Pecos Valley Irrigation Company has recently built a dam across the Pecos 7 miles above Eddy. This dam is 45 feet high, and sets the water back in the stream about 7 miles. While I was there the gates of the dam were closed and the water held back for several days, which gave a good opportunity for seeing the bottom of the river. The dam was perfectly tight, no water passing it. Seven miles below I measured over 300 cubic feet of water per second that had come into the channel below the dam from the springs in the bottom and along its sides. Wherever rock could be seen in this part of the river it was conglomerate.

In addition to the springs in the Pecos country, there are numerous pools of fresh water. Some of them are on the table-lands above any water course or storm-water channel. Some of these pools are but a few feet in diameter, others frequently cover a few acres; the water in them is cool and fresh, generally containing a great deal of lime and gypsum. The water in many of them has the appearance of being very deep; the surface of the water in these pools is usually a few feet below the surface of the ground. These small and deep pools are called "China holes" by the people, from their supposed great depth. At Roswell we were informed of the existence of several small bottomless pools, which lie on the east side of the Pecos, about 12 miles southeasterly from Roswell. An examination of several of these pools and small lakes was made, but, unlike those seen on the flat prairie, these were at the foot of a ledge of gypsum rock about 125 feet high. The surroundings of some of these pools resemble an immense circular excavation from 200 to 300 feet in diameter, cut down through the perpendicular face of the ledge to the bottom and extending into the water, and extending back into the ledge about one-half to three-quarters the diameter of the circle, resembling an immense well 300 feet in diameter, cut down through the ledge, and so near its face as to leave no wall on one-third of its periphery. The walls seem to extend nearly perpendicularly into the water. The water is very clear and transparent; the rock sides can be plainly seen a considerable distance below the surface. There is a dark hue to the water, giving it the appearance of great depth. The largest of these pools covers about 80 acres; two others are somewhat smaller in extent. These larger pools lie at the foot of the ledge, but not in a recess like the smaller ones. There is only a small amount of water flowing from any of these pools, that which does escape contains gypsum and lime in large quantities which has been precipitated by evaporation until it has built up large mounds or banks of earthy material which slope gradually from the edge of the pools. There are millions of cubic yards of material in these deposits. It is the opinion of the people who live in that vicinity that these pools are connected with each other and with a subterranean body of water by underground passages, which are large enough to allow large fish to pass from one to the other and to some other place for the winter. It is reported that in summer time they all contain fish (bass), but in the winter none are to be found. Our examination of these pools or lakes, as they are commonly called, show that no two of them are on the same level, in fact some of them differ as much as 60 feet in elevation; consequently they can not be connected by underground passages, as supposed, nor is it probable that they are connected with any large underground lake, from the fact that when the rim of these pools have been cut down (as two or three of them have been, 3 or 4 feet) the water discharged was just simply that due to what was in the pool above the bottom of the opening, nor does any more water flow from the opening than before the surface was lowered. The depth of these pools as determined by us was a surprise to the people as well as to ourselves, for they all looked very deep. We had been told that cowboys had tied four picket ropes together and failed to find bottom, and also that a Dr. Alexander had sounded one of these pools with two spools of thread tied together (400 yards) and failed to reach bottom. Providing ourselves with a 4-pound lead sinker and 1,500 feet of line, we made a sounding off the edge of what appeared to be a projecting rock in one of these pools (the place where the cowboys had sounded with four ropes); we found only 48 feet of water at this place. The two most northerly pools were sounded by us all over the bottom in a boat obtained at Dr. Alexander's place. Mrs. Alexander told us of the doctor's sounding one of them with two spools of thread, and said the other had been sounded without finding any bottom. We found the greatest depth of these two pools to be respectively 34 and 16 feet. On the bottom of each was found a thick growth of dark green moss; this was what gave the water the appearance of being so deep. I think it quite probable that some of the pools were deeper than those we sounded, but I doubt if any of them exceed 90 feet. These pools and the China holes found on the dry prairie present interesting subjects for the study of the effect that water has in dissolving and disintegrating gypsum and lime rocks. Some of these China holes are of recent formation. Cattlemen who have been riding over the country report that some of them have been formed during the past twenty years. They first appear as a fissure or crack in the surface of the ground and gradually cave in and widen until cattle can get down into them for water.

The Mescalero ridge was visited at a point east of Eddy. At this place it is about 160 feet high and 800 feet above the Pecos River; this ridge is about 150 miles long and marks very distinctly the western boundary of the Llano Estacado or the great Staked Plains of western Texas. At the point visited the ridge is composed of limestone, which rises to the north, and to the south it gradually disappears until nothing is seen of it at the Texas line. Immediately at the top of the ridge begins the great plains, which slope very gradually to the east. It is reported that water can be found on the surface in places on these plains and in wells ranging from a few feet in depth to 80 or 90 feet. The country between the base of the ridge and the Pecos slopes gently to the west until near the river, where another ridge appears in places, but not so well defined nor as high as the Mescalero. The second ridge is composed of limestone and gypsum. Some portions of it is solid gypsum with streaks of red clay between the strata. The country between these ridges is occupied as a grazing country. Water is found only by digging. The Eddy-Bissell Cattle Company have two rows of wells about 12 miles apart, and an abundance of water is found in places 16 feet below the surface in gypsum rock. A single well furnishes water for 4,000 head of cattle. Along the base of the Mescalero Ridge is a deep deposit of sand, gypsum, and lime, about 10 miles in width on which little vegetation grows; this is an accumulation of material brought there and deposited by the action of the wind. Considering the presence of so large an extent of sand and the absence of any running or permanent water on the surface, this strip of country can be occupied only for grazing purposes.

No attempt has been made in this part of the Pecos Valley to find artesian water, except within the last few months. Last fall a well was put down at Roswell; they found flowing water there at a depth of 207 feet in a drift formation mostly clay; the water comes from a thin stratum of sand. The water is soft and has a pressure at the top of the well of only 2½ pounds per square inch. The pipe is 1½ inches in diameter, and discharges 1½ gallons per minute. Although the flow is small, the well is a great boon to the town, as it affords the only good water for domestic use in that section of the country. A mistake was made in casing the well; had it been done properly the flow would have been much greater. Other wells are going down in that vicinity, and better results may well be anticipated. We are lately informed that a number of wells have been put down at Roswell which have the same general characteristics as the one described, although many of them have a much stronger pressure. The Hagerman artesian well is located on a high bluff just across the river, opposite the town of Eddy. The contractor went down 600 feet, which was the limit of his machine, and struck plenty of water, but none that would flow. It is intended to extend this well to at least 1,500 feet with the hope of striking a good flow of artesian water. Another bore has been commenced on the west side of the river, in the center of the Eddy Park, with reasonable prospects of obtaining flowing water. The Hagerman well shows the following strata up to September 11, 1891:

	Feet.
Solid rock, limestone	5
Conglomerate bowlders (concrete)	145
Red clay	3
Hard limestone	6
Red clay	20
Alternate stratas of gypsum, clay, and hard shaly rock that looked and smelled like granulated cemented oyster shells, layers about 15 feet in thickness	300
Mixture of gypsum, alum, and salt	75
Gypsum, oyster shells, and salt	46
Total	600

The company well at South Roswell, New Mexico, has the following report of strata:

	Feet.
Soil and top dirt	4
Limestone chalky formation	22
Blue and yellow clay	50
Lime rock, fine grained	10
Sand rock with pebbles	25
Red clay with grit	50
Lime rock, porous	22
Sand rock	4
Clay and gravel, mixed	100
Lime rock with holes and crevices	42
Total	329

There is plenty of water in this last well near to the top, but no flow as yet.

The following artesian wells are in operation at Roswell:

Jaffa & Prager: Depth, 207 feet; 1½-inch pipe; flow, 2½ gallons per minute.
Main Street: Depth, 165 feet; 1½-inch pipe; flow, very slight.
S. Truxton: Depth, 156 feet; 1½-inch pipe; flow, 3½ gallons per minute.
J. C. Lea: Depth, 165 feet; 2-inch pipe; flow, not definitely taken.
Cosgrove: Depth, 185 feet; 1½-inch pipe; flow, one-half gallon per second.

Flowing water was also struck at Mr. Barrett's, but upon withdrawing bit the well caved and was abandoned.

I have herein noted what appears to be the most prominent features of this part of the country pertaining to this investigation. There now seems to remain a necessity for a brief discussion of the question of the probabilities of an artesian and underflow, and the utilization of these subterranean waters.

The area included in the drainage into the Pecos River from the west, including that of the Rio Hondo and that of the other tributaries to the south as far as the Texas line, is about 7,000 square miles. The average annual rainfall on this section is probably in the neighborhood of 12½ inches. I estimate that this portion of the Pecos River receives 1,000 cubic feet of water per second from springs underflows, and an average of 500 cubic feet per second from surface water that flows off the 7,000 square miles of drainage area.

These estimates being correct, we have a run-off in the Pecos River of 23 per cent of all the water falling on the watershed; that is, the annual discharge of the Pecos at the rate of 1,500 cubic feet per second would cover 7,000 square miles 2.9 inches deep, against 12½ inches by the rainfall. Here is a loss of 77 per cent. Part of it is due to evaporation which passes into the air, and the remainder going into plant growth and into the earth. The percentage of run-off in the Pecos Valley is considerable less than in Massachusetts and several other places where observations have been made. It is to be inferred then that the percentage not accounted for here exceeds the average. This being true, we then must have an underground flow greater than the average to carry away a portion of the 77 per cent of the quantity unaccounted for.

On account of the great amount of water that escapes in springs at the bottom of the limestone, I hardly think it possible to find artesian water with great pressure in the neighborhood of these springs, especially in the limestone; it may be found in the conglomerate. The drill only can settle this question.

The nearest borings that have been made in this part of the country are on the Texas and Pacific Railroad at Pecos City and Toyah, some 80 or 90 miles south. At Pecos City and vicinity there are sixteen flowing artesian wells; the largest flow is reported to be 60 gallons per minute. The wells are from 150 to 250 feet deep in the drift, some of them just reaching the conglomerate. There are two flowing wells at Toyah. The details concerning these wells and others in the same vicinity are given by Mr. Roesler in his report published in Ex. Doc. No. 222, Fifty-first Congress, first session (see pages 293–297).

I doubt if water in sufficient quantities will be found in the conglomerate for irrigarion purposes; it may be in the limestone, when it is confined to give it the requisite pressure.

It does not seem advisable to employ expensive methods for intercepting the underground flow when so large a percentage of the water that sinks in the mountains and foothills reappears again and can be used for irrigation. The water should be used before it sinks when it can be done so to advantage, otherwise after it comes to the surface in the lower valleys.

There are many excellent opportunities for storing flood and storm waters which can be done at a reasonable expense. The only question regarding the storage of water here is the possibility of a large loss by infiltration into the lime rock, which is almost everywhere present, and very near the surface in most places where reservoir sites are to be found.

The amount of agricultural land in the Pecos Valley that is capable of being reclaimed by irrigation greatly exceeds the water supply even if it was all saved.

Owing to the fine climate permitting the raising of nearly all of the products that can be grown in a semi-tropical climate, including the fruits (excepting the citrus) and the large and constant water supply, the Pecos Valley will be the largest and one of the richest, if not the richest, and best cultivated valley in New Mexico. The irrigable lands are being rapidly taken up and occupied by English-speaking people, a large percentage of whom are from the Northern and Eastern States.

While in Santa Fe we found the Territorial legislature in session, which afforded an opportunity to obtain information from parts of the Territory that could not be visited. It seems to be the general opinion that the people of New Mexico are too poor to do much more than they have already done to develop the agricultural resources of the country by means of irrigation. Thus far, with a very few exceptions, irrigation in this Territory has been confined to lands lying close to the streams which have required no great expenditure of labor, money, or engineering skill to construct their irrigation works.

Irrigation developments in the Territory would now seem to run along the lines of larger enterprises backed with a considerable amount of capital, which latter must of course come from outside New Mexico itself. Some doubts of the wisdom of this may properly be expressed here. Already a number of such projects have been designed. Two are now under way and to be ready for irrigation in the spring of 1892. Two other enterprises have recently been completed and are now in successful operation, for irrigation purposes. There are grave reasons for expressing a doubt as to the returns on capital required and also as to a sufficient water supply, without the aid of large storage reservoirs, in considering some of the pending projects designed for New Mexican irrigation. The agricultural lands lying above the valley of the Rio Grande, are of fine character, but the expenditure at present of large sums for the construction of the expensive high line canals that would be necessary to effect their reclamation does not seem to be desirable. Of some plans for bringing the mesa under irrigation, it may well be questioned if a proper water supply can be obtained.

It is estimated that there is a sufficient amount of good agricultural land lying in the immediate valley of the Rio Grande to consume all of the water of that stream even if its flood and storm waters were stored in reservoirs and retained for use during times of low water. In making the suggestion that it would be more economical, and in the natural order of things to utilize the water to serve the lower lands first, the reply is, that the larger the enterprise, and the more money involved in its development, the easier it is to secure the money from abroad; besides, the speculation in lands obtained from the Government in various ways has a charm for the investor. The lands in the valleys are mostly taken up, or are grant lands; so at present there is little attention being paid to the more simple and inexpensive methods for extending irrigation in New Mexico, and yet, in that direction, there is much progress to be made.

The necessity of utilization of subterranean waters for irrigation is not attracting any special attention here.

Since our first investigation several flowing artesian wells have been struck in the Territory; two near Springer, the others at Roswell. They all have very small flows; not sufficient for irrigation to any extent. The Springer wells have quite a pressure when confined; the exact pressure has not been determined. It has been reported that it was sufficient to raise the weight of two men on a three-inch pipe, which will probably be 40 or 50 pounds per square inch. The particulars concerning the Roswell wells are already noticed in this report.

UNDERGROUND WATER SURVEYS.

We have made with considerable detail an investigation of the extent and availability of the underflow in a few localities in Nebraska, Kansas, Colorado, and Wyoming. The valleys of the Platte and Arkansas rivers were selected as affording the best opportunity for studying the relation between the surface and underground waters as they exist in these valleys and the higher country on each side.

The plan adopted in making this form of investigation was to determine the elevation of the surface of the underground water on lines each side of the river channel. These lines were extended back from the streams far enough in most instances to reach the table lands, or extending from 15 to 40 miles each side, nearly at right angles to the stream. The elevations of the surface of the country and the water table underlying it were obtained by leveling over these lines, and wherever wells or bores had been sunk to water, the depth from the surface was either measured or obtained from people residing in the vicinity of the surveys.

Eight of these lines were surveyed in the valleys of the Platte and Arkansas rivers; five in the Platte and three in the Arkansas. A similar line was run across the valleys of the Loup rivers, which is an extension in a northeasterly direction of the Lexington line. This line was surveyed at the request of Assistant Geologist Hicks, for the purpose of assisting him in his geological work in that section.

A line from Sterling east and connecting with the Big Spring line was also surveyed. This survey was made to determine the question of the continuity of the so-called sheet water between the South Platte and the Frenchman, a branch of the Republican River. The line was also surveyed in Wyoming, paralleling the foothills between Cheyenne and Fort Laramie. The object of this survey was to determine whether or not a continuous supply of subterranean water can be found under a rolling country, which is here and there crossed by small drainage channels that carry more or less water in their upper section during the entire year.

The following report of Assistant Engineer Follett, with accompanying profiles in the several appendices, give the details of these surveys, which affords an opportunity for studying the subject of the underflow waters in the Great Plains regions.

WASHINGTON, D. C., *December* 15, 1891.

DEAR SIR: I hand you herewith eleven tracings showing a plat and profile of as many lines run by us last winter and spring across the drainage of the Platte and Arkansas rivers. I also hand you a sketch map showing the location of these lines. Reference to it will show that one line was run in Wyoming, two in Colorado, five in Nebraska, and three in Kansas. The line also shows the location of a barometric line run by you from Norton to Dodge City, Kans.

The purpose of these lines was to study the so-called "underflow" theory. This theory is: That a large portion of the Great Plains is underlaid by a stratum of water-bearing sand and gravel continuous with the beds of the main rivers and fed by the water from the mountain drainage which comes down these main streams; that this water-bearing stratum is of great thickness; that its water is practicably inexhaustable, and could it be brought to the surface would irrigate a large portion of the country overlying it.

With the exception of some remarks relative to the continuity of the water-bearing strata and their source of supply, this report is intended to be simply descriptive, telling you in detail what I found, and leaving to you the deductions. The lines are intended to test the statement that the water-bearing stratum is continuous, and corresponds to the bed of the main streams. They were hurriedly run with the assistance of only two men, a driver and a rodman. Distances were obtained by stadia reading, elevations by vertical angles, and direction by compass. I had my rodman mounted, and used a team and driver to transport myself and transit.

The profiles represent about 860 miles of line. They were run at an average speed of 20 miles per day of actual instrumental work. All elevations are reduced to sea level, and the levels were checked, whenever possible, by railroad elevations at those stations which the lines reached. Vertical angles leave a rather large margin for possible error, which I found in one or two lines. Where checks were had the error was eliminated, and where not had, the probable error obtained from the work done just before and immediately after was applied.

Your instructions to me were to obtain the relative elevation of the ground and of all permanent water crossed, the material in which it was found, and the strata passed through in digging the wells. Also, to obtain particulars as to the cost of wells, the cost and efficiency of the windmills and pumps used, the amount and quality of water obtained from wells, and the use to which it was put.

I prepared and used the following blank in gathering the desired information about the wells whose surface elevation was obtained:

Well examined by W. W. Follett on —— line in ——.
No. of well ——. When examined ——.
Location, ——.
Owner, —— ——. Post-office, ——.
When put down, ——. Kind of well, ——.
Size, ——. Depth, ——. Distance to water, ——. Depth of water, ——.
Amount of water, ——.
Did water raise when struck ? ——.
Is supply changing ? ——.
Strata passed through, ——.
Quality of water, ——. How raised, ——.
Kind of mill, ——. Stroke, ——.
Cost of well, ——. Cost of pump, ——. Cost of mill, ——.
Cost of repairs to mill, ——.
Maximum amount pumped per day, ——. Used for, ——.
Elevation of surface, ——. Elevation of water, ——. Elevation of bottom, ——.
Remarks, —— ——.

It was my aim to connect with a well once in 2 miles whenever possible. Where the profiles show an interval between wells longer than this it is because none could be had. On some of the lines where the country was thickly settled, as on the Grand Island and south end of the Lexington lines, I did not attempt to examine all the wells close at hand. In some places there were two every half mile. Two hundred and sixty-four wells were examined and the answers obtained are attached to this report. (See Appendix No. 25.)

The plat across the bottom of each profile shows the country the line runs through. The line surveyed is the one having small marks on it at intervals. The squares are sections and are generally a mile square. Whenever possible, wagon roads were followed. These generally ran on section lines. The profile is projected up from the platted line below. The heavy line with diagonal shading under it represents the surface of the ground, each portion showing the elevation of that point of the surveyed line, directly below it on the plat.

The spaces between the horizontal lines each represent 50 feet in vertical height, and the number on each alternate line shows its height in feet above sea level. The heavy vertical lines show the wells examined, with the top and bottom at their proper sea-level elevation. By comparing the length of these lines with the distance between the 50-foot horizontal ones, the depth of each well can be estimated. The thickness of the strata passed through are shown by the short horizontal marks on the well lines. The names given the material in these strata are descriptive of their physical form, and do not purport to be their proper geological titles.

The horizontal line shading on the profile shows the elevation of the water surface in the wells, pools, or streams crossed. In many of the wells the water supply is artesian in its character, rising above the point where it is struck, although not enough (except in wells 164, 165, and 198) to flow over the surface. In all cases the shading shows the point to which the water rises. In all wells, unless otherwise noted on the profile, the main water supply is found at or near the bottom.

These profiles are so platted that the observer is supposed to be standing with his back to the west and to be looking east or down the drainage of the country. As the Frenchman line runs east and down the drainage, it is platted with the west end at the left and the observer is looking north.

The following is a detailed description of the several lines run.

CHEYENNE LINE.

(See Appendix No. 2.)

This line extends from the headwaters of Duck Creek on the Colorado-Wyoming line to the North Platte at Fort Laramie, and is 110 miles long. It crosses Crow Creek at Cheyenne, and then runs northward through a barren region uninhabited except in the valleys of the three or four small streams crossed.

South of Cheyenne is a sandy country in which water has been found in reasonable quantity wherever wells have been put down. Two miles south of Cheyenne is a small artesian well whose water comes from coarse gravel under hard white clay. The flow is but 1¼ gallons per minute and the pressure is small. Two or three wells in Cheyenne have been put down deep enough to strike this vein, but the ground is so high that the water will not flow.

The surface wells in Cheyenne are all artesian in their nature, although not flowing. The water of each well varies much in quantity and in height at different seasons. The owner of well 194 said that in July or August his well, 33 feet deep, would have about 8 feet of water in it, and could be pumped dry in four or five hours with a common hand pump. In the winter and spring the water would come almost to the top of the well and could not be lowered with the pump. All wells in Cheyenne are said to be of this nature.

At well 195, about 5 miles northwest of Cheyenne, on ground 180 feet higher than the city, water is found in gravel 100 feet below the surface. It rises over 50 feet and can be lowered only 10 feet by pumping, although the well tube is but 4 inches in diameter, and 30 gallons per minute have been pumped from it for twenty-four hours or more at a stretch.

On leaving Cheyenne the line crosses the divide between the North and South Platte rivers. The country is rugged clay and limestone hills. Water has been reached on the divide in but two places along the line run. The first well (well 196) is in a deep depression where water was found in quicksand 75 feet below the surface. This bed of quicksand was penetrated 120 feet in an effort to get artesian water. The pipe got fast and the hole was abandoned without finding the bottom of the quicksand. The second well on the divide is about 1¼ miles south of Lodge Pole Creek, and the water is in sand on a level with the creek, but 45 feet below the water in well 196.

On leaving this divide the country falls rapidly to the northward. With the exception of very narrow valleys on the small streams crossed the country is sterile and barren. No attempts have been made for wells except in these valleys close to the channel of the streams, and then water is found in drift on the limestone a few feet below the surface.

At Cheyenne plenty of soft water is obtained right in the Creek Valley, but the Union Pacific Railway put down a well at their water tank, which sits upon the clay bluff north of the Creek Valley, some 20 feet above it and 500 or 600 feet distant from the creek, reaching a point over 80 feet below the bed of the stream, and obtained but a small quantity of water, so alkaline as to be unfit for use, showing that there is no sheet of water here level with the creek.

Down the valley of the creek from Chugwater to Bordeaux water is obtained level with the stream and close to it, but nowhere at any distance from the channel.

After leaving the Chugwater at Bordeaux no water of any amount is found until the valley of the Laramie is reached. The well at Eagle Nest (well 201) furnished at its best about 50 gallons per day of water seeping in through sandy clay marl. It has long since been filled up and abandoned. At Fort Laramie the delta of the Laramie and North Platte presents nothing unusual. Water is found in gravel at about the level of the rivers.

This line, taken as a whole, is negative in its results, so far as showing the existence of "underflow" is concerned. It is hardly fair, however, to give this line equal weight in the discussion with those farther east, as it lies so far west as to be practically removed from the Great Plains. It is almost in the foothills.

STERLING LINE.

(See Appendix No. 3.)

This line runs from Akron, Colo., northward to Lodge Pole Creek in Nebraska, striking it about 10 miles west of Sydney. At Sterling, Colo., it crosses the valley of the South Platte on an angle of about 45 degrees, and is about 75 miles long.

Akron is situated on a plateau some 600 feet above the South Platte River at its nearest point. No regular stratum of water-bearing material has yet been reached under this plateau. At Akron a supply of 12,000 gallons per day has been developed from a thin vein of fine sand about 75 feet below the surface by drifting tunnels in the fine clay under the sand and topping it at various points. In other wells around Akron water, when found at all, is obtained in thin veins of sand or sandy clay marl. Many dry holes have been put down.

Going north from Akron the plateau continues for about 12 miles, gradually falling toward the South Platte. As at Akron water is hard to get when found. It is seep water in soft clay marl, sandy marl, or very thin veins of sand.

At 12 miles from Akron sand hills are entered, and they continue until the valley of the river is reached. These hills are probably formed by sand blown up out of the Platte, and, as is usual in hills so formed, are underlaid at an elevation but little below the lowest depressions by hard material. They are unfit for agriculture and so have but few inhabitants. Water is found in the deepest depressions a few feet below the surface on top of clay or sandy clay. No continuous vein of water can be traced. The supply from the local rainfall is quickly drunk up by the sand, through which it percolates slowly when the grade is steep.

North of Sterling a small divide is gone over which furnishes near its summit water in large quantity close to the surface in a little arroyo. The line then crosses Cedar Draw. A well just on the south side of the draw reaches a strong vein of water, artesian in its character, in gravel 40 feet below the bottom of the draw. In the draw itself is a pool of permanent water whose surface is at the same level as that to which the water in the well rose. The general surface of the draw is clay and clay overlays the gravel in the well. It is probable that the pool is supplied from the gravel stratum through a break in the clay. The profile makes it appear that this water is level with the water of the Platte. It is level with it at Sterling, but the Platte at the mouth of the draw is some 60 or 70 feet lower than the water in this pool.

North of Sydney Draw the climb is made up a gradual slope to the top of the divide between the South Platte and Lodge Pole Creek. Water is precarious, but is found in sandy clay or in sand. Some 2 miles east of well 230, down the drainage, is a spring. This is probably the outcropping of the stratum which furnishes the well with its water.

Going up the slope north of well 230 water is found in but few places. When found it is in sand in some draw and is either obtained near the surface or in springs.

Five miles south of the Colorado-Nebraska line a high plateau is reached which extends north ten miles to Sydney Draw. On this table land water is scarce. But few wells have reached it. Many have been failures. In those in which water was struck it was found in this vein of sand on top of hard clay marl or in sandy clay marl. The supply is small and at no definite distance below the surface.

Sydney Draw, a depression some 4 miles wide and 230 feet below the adjacent country, has no surface water in it. At the point crossed by this line it furnishes a good supply of water in clay marl 80 feet below the surface. On its south side the escarpment of the plateau furnishes many weak springs coming out of a deposit of magnesia and cemented gravel about half way up the slope, or 100 feet above the bottom of the draw.

Between Sydney Draw and Lodge Pole Creek is a broken country of clay hills devoid of surface water. No attempts for wells have been made. On Lodge Pole plenty of water is found close to the creek in a gravel stratum level with its bed.

Like the Cheyenne line, this one is negative in its results. It lies at about what may be called the northwestern limit of the Great Plains. The plateau country both north and south of the Platte is so high above the river that a deep hole would probably encounter rock in place far above the river's level.

FRENCHMAN LINE.

(See Appendix No. 4.)

The Frenchman is one of several streams which form the Republican River. This river is what is called a plains stream, that is, one which rises on the plains. It carries no mountain drainage whatever. The upper portion of all its branches are at first merely storm water channels, but at some point in their course water appears in springs and then begins to flow. It is constantly added to until the whole river is formed. The principal branches of the Republican on the north side are, beginning at the west, the Frenchman, Stinking Water, Red Willow, Medicine, and Muddy creeks. These all rise on the plains and all gather a good flow in the first few miles below where the springs appear. Twelve miles below its source Medicine Creek carries 30 cubic feet per second minimum flow and I am told that the others carry the same or more.

It is generally believed that these plains streams derive their water from the mountains through gravel strata, and it is locally supposed by all that the branches of the Republican on its north side derive their water from the Platte River. The data obtained from the Big Spring and North Platte lines (described further on in

this report) was not such as to settle this question, and so you instructed me to run
a line from Sterling, Colo., eastward to the headwaters of Frenchman Creek. This
is the Frenchman line, extending from Sterling 65 miles east.

Running eastward from Sterling, the first 8 miles after crossing the South Platte
was barren sand hills. The eastern edge of these forms the water shed between the
Platte and the Frenchman, and is 680 feet above the Platte. East of the sand hills
is a rolling prairie country sloping gently to the east. Three miles east of the summit
the first well is met. It is 205 feet deep, but the water supply comes from a vein of
clay marl at 120 feet. But little water comes from the bottom, although it is on
gravel under sandstone. The water supply is small. This is the history of the wells
for the first 12 miles east of the divide, a small quantity of water seeping in through
clay marl or sandstone. Even where gravel is reached, as in the well just cited, no
large amount is obtained.

The dry storm water channel, which heads directly east of this divide and finally
forms the Frenchman, is of coarse gravel. In many places there is water at the
bottom of this gravel on the underlying clay, and even within 3 or 4 miles of the
summit it is almost permanent, failing in very dry years only. All the way to the
east shallow wells into this gravel are found, some of them said to be permanent. None
are put on to the profile as they would tend to confusion. Thirty miles east of the
divide this water, stopped by a clay reef across the channel, comes to the surface and
forms the "Julesburg waterhole." This has never been known to go dry, although
getting low in 1889 and 1890.

About 13 miles east of the divide the wells begin to reach an abundant supply of
water in sand or gravel under what is locally called "magnesia." It is seemingly
clay strongly charged with lime and mixed with gravel, the whole being more or less
solidly cemented together. On the profile I have called it clay marl and magnesia.
Well 247 was the first one that the line struck which went to the "sheet water," as
it is locally called. The bottom of this well is 100 feet above the Platte River at
Sterling. The wells to the eastward show that the fall of this stratum is about 18
feet to the mile. This same gradient carried westward would throw the vein about 500
feet above the Platte at Sterling. As the fall of the Platte is but 8 feet per mile it is
easily seen that there is not much chance of this water coming from it. It is not ad-
missible assumption that this vein becomes nearly level west of where it has been
topped, in which case the Platte might possibly catch up with it somewhere about
Fort Morgan. As shown by the profile its tendency is to increase its gradient to-
ward the west rather than to decrease it.

In the neighborhood of Holyoke the regularity of this slope is broken. Well 203
is the one whose water is farthest from the line of regular slope.

At Holyoke the Burlington and Missouri River Railroad has put down a well to a
second vein of water underlying this, and artesian in character, rising to about the
level of the upper vein. They have pumped 60 gallons per minute for eighteen hours
from the 16-inch hole without lowering the water.

East of Holyoke the wells all reach this upper vein. The gradient of the stratum
flattens to about 10 feet per mile while the surface falls 16 to 18 feet per mile. Fi-
nally the two come together in the channel of the Frenchman, 3 miles east of the Col-
orado line. Here water begins to flow in the creek.

Careful study of this line gives almost absolute conviction that the source of this
water is not the Platte, and as the river cuts down far below the westward projec-
tion of the water-bearing stratum it can not be from the mountains. The only infer-
ence is that the source in local and is the rainfall along near the crest of the divide.

BIG SPRING LINE.

(See Appendix No. 5.)

The Big Spring line runs from the North Platte, 18 miles north of Big Spring, 52
miles south to the headwaters of Frenchman Creek at the east end of the French-
man line, crossing the South Platte at Big Spring. The country between the two
Plattes is a high table land broken up into ragged bluffs on the north. On the
higher portion of the plateau the water supply is derived from a deep-lying gravel
stratum under thin rock whose waters are artesian in character. The water in well
No. 4 rose about 100 feet above the point where it was struck. It is locally believed
that this vein is continuous with the two rivers. Examination of the profile shows
this assumption erroneous. The North River is 80 feet lower than the South and the
water in well No. 4 rises to a point 160 feet above the North Platte. Near the
southern edge of the table land water is found in sand or in sandy clay in good
quantity, but not rising very far in the well. Well No. 10 (not shown on the pro-
file) lies in the bluffs just north of the South Platte, some 8 miles northeast of Big
Spring. A large supply of water, rising 8 feet in the well, was struck in gravel under
sandstone. The bottom of this well is a few feet above the Platte.

The big spring at the station of that name comes out of the bluffs some 15 feet above the river. It comes out of or from under cemented gravel, and is probably from the vein supplying well 10.

South of Big Spring the country traversed is typical of the Great Plains. The line lies 1 mile east of the Colorado-Nebraska State line and strikes Venango on the Burlington railroad. At the northeast corner of Colorado the lines strikes what is known as the State corner spring. There are several other good springs southwest of this one on the same or higher level. It flows about 5 gallons per minute and is 180 feet above the Platte. It comes out of sandy clay in a long sandy arroyo, which furnishes water below the spring within a few feet of the surface. This group of springs is probably fed by local rainfall and has no value in the study of the "sheet water" of the locality.

Well 11 is the first one struck by the line south of the Platte Valley. Its water supply comes from a layer of gravel under cemented gravel 25 feet below the level of the Platte, but the water rises over 70 feet in the well. This is typical of the wells in the neighborhood.

At Venango well 23 is put down to what is locally called the third vein. As it is overlaid with a thin layer of rock and as its water rises some 40 feet above that of the second vein, it is undoubtedly a separate stratum. The well has been pumped 80 gallons per minute for one hour without materially lowering the water in the 5-inch hole.

From Venango south the water-bearing stratum rises, its level in well 23 being 3,390 feet above the sea level and the south end of the line (see well 263) 3,472. This elevation of 3,472 is 110 feet above the South Platte at Big Spring and is on the vein which supplies the Frenchman, the water of the latter stream coming to the surface about a mile and a half southeast of well 263. The wells on the south end of this line and on the Frenchman are undoubtedly in the same vein or veins and show that the line of greatest dip of the strata is north of east.

NORTH PLATTE LINE.

(See Appendix No. 6.)

This line runs from the head of the South Loup, 23 miles north of North Platte, 52 miles south to Medicine Creek, 3 miles east of Wellfleet. Owing to détours, the line run was 60 miles long.

The Loup rivers and their tributaries are plain streams rising in the eastern part of an extensive sand-hill country northwest of North Platte. At the point where this line strikes the South Loup Valley, water stands in pools and just begins to run. After reaching the table-land south of the Loup, the country is rolling prairie for 10 miles. Then the sand hills are entered and they continue to the Platte Valley. The water in the Loup is 160 feet above that of the Platte. Nearly all the wells examined reach water not artesian in character in sand or gravelly sand about level with or slightly below the Loup. Wells 47 and 51 go down to a deeper vein and get water from gravel (under clay in 47 and sandstone in 51), which rises to the same level as the upper vein.

The town of North Platte lies between the two rivers about 3 miles above their junction. The valley is six miles wide. The channel of the south river is 10 feet above that of the north, and in November, 1890, when this line was run, was dry, the water level being 4 feet below the river bed. This valley is all a deposit of river sand and gravel and, if water moved freely in sand, it would be found on the same level across this valley. Such was not the case. The first water struck on the north side of the valley was in White Horse Creek. Its elevation was 2,788 feet above sea level, but it was crossed three-fourths of a mile east of the crossing of the rivers. The water in the North Platte was at elevation 2,788. That of the water in the wells at North Platte and in the South Platte was 2,792, and in Fremont Slough 2,797, thus showing a difference of level of 9 feet in less than 4 miles square across the drainage.

South of North Platte the line strikes a high table-land over 200 feet above the Platte Valley. The soil is sandy, becoming hard, fine sand (loess) at the south end, where deep cañons are cut into it, with almost vertical sides. Some of them are over 100 feet deep. Water on the plateau is generally found under cemented gravel in fine sand changing to gravel, and, except in 1 or 2 wells, is not artesian in character. Immediately south of the valley, the level of the water-bearing stratum is practically that of the Platte, gradually falling to the south. The south end of the line on Medicine Creek is 110 feet lower than the Platte. As stated before Medicine Creek has here a minimum flow of about 30 cubic feet per second. This water comes out of the fine sand near the head of the creek, and from stratum of cemented gravel lower down. The stream is similar to the Frenchman.

LEXINGTON LINE.

(See Appendix No. 7.)

This line runs from the South Loup, 30 miles north of Lexington, to Oxford, on the Republican, 36 miles south and 6 miles east of the former place.

From the Loup to the edge of the Platte Valley, 8 miles north of Lexington, the country is hilly and sandy. The water in all wells examined in these hills rose in the wells and was found in quicksand, changing to gravel under clay or cemented gravel. The water-bearing stratum at the north end is about 80 feet above the South Loup. There are some springs along the south side of the river coming from this stratum. The Loup is some 10 or 15 feet lower than the Platte at Lexington. At well 63 a hole was put down to a point 100 feet lower than the Platte, but no water was found below the regular vein, which at this place is between 40 and 50 feet above the river.

The valley of the Platte falls from its northern edge towards the river about 5 feet to the mile, and the water found in large quantity in sand and gravel near the surface falls the same.

South of the valley, which is here 15 miles wide, the line runs up onto a plateau whose northern edge is about 150 feet above the river, and for the first 15 miles south it averages up nearly level. It then falls off about 30 feet to the mile to the Republican River. The water does not rise in the wells. Under the level portion of the table land an abundant supply is found in sand or gravel. The stratum at the north end is about level with the Platte and falls to the south 10 feet to the mile for 18 miles. At this point the slope increases to 15 feet to the mile, coming down to the surface of the Republican at Oxford. South of this break in grade, water becomes uncertain and small in quantity where it is found. The sand and gravel stratum ceases and the water comes from sandstone or thin veins of sand and gravel under sandstone.

LOUP LINE.

(See Appendix No. 8.)

Starting from the north end of the Lexington line, this line runs 55 miles northeast to the North Loup near Burwell, Nebr., crossing in its course the South Loup, Mud Creek, Clear Creek, and the Middle Loup.

The country traversed is all broken and sandy, except at the valleys of the Loups. A large proportion of the inhabitants are foreigners, and the information about wells is not so reliable as that obtained on the other lines.

This line runs somewhat east of what would be right angles across the drainage of the country. The North Loup at Burwell is 150 feet lower than the Middle Loup and 250 feet lower than the South Loup at the points where the line crosses them.

An examination of the profile will show that the loops all seem to have cut down into and below the water-bearing stratum of the country. Comparing this profile with the north end of the Lexington line, it is seen that the water-bearing stratum immediately south of each Loup is higher than it is north. The stratum falls to the northeast, not rising with the country north of the streams crossed. The water is found in small quantity in sand or gravel under hardpan and is not (except in rare cases) artesian in its character. In the valley of the North Loup a large supply of water is obtained from a gravel stratum, but this stratum is 30 feet above the river and springs are found at its level along the bank. Well 221 shows its water 60 or 70 feet above where one would expect to find it, but the supply is small and probably local.

This line was run at the request of the chief geologist. The information obtained is not of much value to the engineering branch of the investigation, as the character of the country is such as to preclude the probability of sheet water and such that it could not be used for irrigation even if present in large quantity.

GRAND ISLAND LINE.

(See Appendix No. 9.)

Starting from St. Paul on the South Loup River this line runs 80 miles south to the Republican, passing through Grand Island and Hastings in its course. The sea level elevations of the streams crossed is as follows:

	Feet.		Feet.
South Loup	1,778	Little Blue	1,760
Platte	1,876	Republican	1,630

On leaving the valley of the Loup 3 or 4 miles of sand hills 100 feet high above the river are met. The line then enters a valley which is practically the delta of the Loup and Platte. It falls for about 10 miles to the south, where the ground is 70 feet above the Loup and 30 feet below the Platte. It then rises to the Platte 13 miles farther south. No wells were found in the sand hills. At their southern edge one gets water from a point about 20 feet above the Loup, although a little seep water was had at about the level of the valley to the south.

In the wide valley water is found in large quantity in gravel a few feet below the surface, gradually rising as the river is approached.

Soon after crossing the Platte the country rises about 70 feet and then slopes to the south an average of 3 feet to the mile. Water is found in several layers of sand and gravel separated by thin layers of clay. That from the lower strata rises, all reaching the same level. The north end of this water-bearing stratum is practically level with the Platte and the general fall is to the south, being more than that of the surface, or about 5 feet to the mile, and coming to the water of Little Blue Creek. This stream lies 9 miles south of Hastings and about 100 feet below the general surface of the country.

At Hastings a prospect bore is being put down. In December, 1890, it had reached a depth of 1,145 feet. At 225 feet below the surface the water-bearing gravel was left and a thin layer of clay gave place to some 35 feet of ocher. Shale was struck at 963 feet and continued to the bottom of the hole. At 1,145 feet the bore was in very fine quartz gravel, each grain perfectly spherical. This is probably water-bearing, but is not artesian, at least not enough so to cause flow.

South of Little Blue Creek the country is rolling, gradually rising to a summit 12 miles south, where it is about 200 feet above the creek. It then falls off to the Republican, the last 80 feet of fall being a bluff at the river. The water-bearing stratum or strata show no regularity, except in keeping 75 to 100 feet below the general surface.

Just west of the line a small stream (Willow Creek) heads and runs north into the Republican. It carries a small, perennial flow drawn from the gravel in which all the wells find their water.

GARDEN CITY LINE.

(See Appendix No. 10.)

Three lines were run in Kansas across the drainage of the Arkansas. Owing to lack of time three lines, especially the Garden City line, were not run so far back from the river as they would otherwise have been.

The Garden City line extends from Beaver or Ladder Creek, near Scott City, south through Garden City, to an abandoned post-office called Loco, and is 83 miles long. With the exception of the Valley of the Platte and about 6 miles of sand hills south of it, the country is a moderately level prairie.

This line is nearly south of the North Platte line in Nebraska. If the latter were projected south it would cross the Republican at McCook, and the Garden City line projected north would cross it at Culbertson. Great regularity is shown in the water-bearing strata of both lines, and both slope to the south, seemingly bearing out the underflow theory of a continuous sheet. The elevations of the water-bearing strata on the two lines and at the Republican are as follows:

	Feet.		Feet.
North Platte	2,790	Culbertson	2,550
Medicine Creek	2,680	Scott City	2,920
McCook	2,490	Garden City	2,825

From these elevations it is seen that the north end of the Garden City line is 370 feet above the Republican, directly north of it and 240 feet above Medicine Creek at the south end of the North Platte line. This shows at once the impossibility of a continuous sheet of water. If the Garden City line had been projected north from Ladder Creek it would probably have shown the water-bearing stratum soon pitching northward to the Republican.

In this connection I wish to quote a few sentences from your progress report of last January, which tersely present the facts shown by the north end of this line. You say:

"The sheet water, as shown on the Garden City line, conforms quite well to the theories of the people in that vicinity regarding its extent; but instead of the water-bearing stratum receiving its supply from the river, as heretofore supposed, we find the facts do not justify this theory. The wells on the north side of the river are comparatively quite shallow, and have an abundant supply of water which undoubtedly comes from the west. It will be observed by an examination of the map of seems that the drainage water of the greater portion of the counties of Finney, Scott, Wichita, and Greeley, flows to the east towards this line and sinks in a flat country in Scott and Finney counties.

"Near Scott City there is a depression in the county into which a stream discharges itself whose head is in Colorado. During wet seasons considerable water stands in this depression for a short time, but sinks rapidly into the ground, and this water, without question, furnishes the subterranean water shown on the north end of this profile. It does not come from the Arkansas River, as the slope is in the wrong direction, it being about 2½ feet per mile towards the river. It is more probable that the underflow of the river near Garden City is reinforced from the underground waters coming to it from the northwest."

Wells 178 and 179 are worthy of especial study. These two wells are on a low bench north of the Arkansas River which has been irrigated for three or four years. Since irrigation commenced the water in well 178 has risen 10 feet, and in 179 6 feet, and in December, 1890, still remained at the upper level, although no irrigation had been done for some time. The rise is in sand, the bottom of both wells being in gravel. This phenomenon seems to have a direct bearing on that portion of the underflow theory which assumes that water moves rapidly through sand and gravel.

At well 177 is a reservoir holding about 100,000 gallons. This can be filled in twenty-four hours by the 14-foot Holladay windmill, the lift being only 12 feet. The pump cylinder is 8 inches in diameter and has a 12-inch stroke. The water is used for irrigation. In the summer of 1890, a very dry year, 7 acres of garden were irrigated from the well by the use of this reservoir. The owner was certain that he was drawing directly from the Arkansas and said that the water in the well varied in height with the river. On examination he found that it had not raised any in the six weeks prior to December 19, 1890, although the river had raised over 3 feet. As the water in the well was then between 4 and 5 feet above that of the river at its nearest point, it is quite likely the rise in the river had not been felt at the well.

The first 6 miles south of Garden City is a sand hill country presenting no especial features. Then a prairie country is entered, which gradually rises to Ivanhoe, 14 miles farther south, where the surface is 110 feet above the Arkansas, and then falls about 2 feet per mile to the south end of the line.

South of Garden City no check was had on the instrumental work, but it was assumed that the same error existed as to the north, and the work was corrected in that way. The corrected levels show the water-bearing stratum, a continuation of that on the north end and falling to the south at about the same rate. If the levels had not been corrected they would have shown it falling about 1 foot per mile more than on the north.

With the exception of 173, all the wells strike water not artesian in character found in coarse sand under clay or in loose fine sand. Wells 172 and 173 are only about 800 feet apart. Well 172 reaches a large supply of water in gravel 200 feet below the surface and under 120 feet of fine sand. In well 173, 160 feet from the surface, the fine sand gave place to blue clay, which lasted for 164 feet, and was underlaid by 13 feet of hard blue limestone. The well was first dug for about 180 feet, and then a 2-inch hole was put down. When the drill had passed through the limestone, at a depth of 337 feet below the surface, a strong flow of water quickly came nearly to the top of the drill hole. When the pump was put on, it was found that the pipe was solidly filled with very fine sand. The well was then dug to 240 feet, the hole being 3 feet square, and another 2-inch hole put down through the limestone. This time the water spouted out of the drill hole so rapidly that it was with difficulty the tools were gotten out of the well. It rose to the level of the water in 172, and has since remained there, although pumped for town use with a steam pump. The quality of the water in the two wells is the same. The two wells are owned by the town of Santa Fe.

As before stated, the water sand still slopes to the south, and it probably comes to the surface at the Cimarron, which lies about 14 miles beyond the south end of the line.

DODGE CITY LINE.

(See Appendix No. 11.)

Starting from Pawnee Fork, this line runs south through Dodge City, Kans. Ten miles south of Dodge the line begins to run to the west and finally ends in the eastern edge of the Meade County artesian basin, 60 miles south and 16 miles west of its northern end.

North of Dodge no well-defined water stratum is found. Many dry holes have been put down. Where water is found it is generally in small quantity. The best wells are in draws or along small streams where the surrounding topography is such as to indicate a supply from local rainfall stored in sand or sandstone. The shales are much nearer the surface here than farther west, cropping on the sides of the deeper drainage channels. They are generally overlaid by cemented gravel, and some springs are found in the gravel, as at Duck Creek and near well 151.

South of Dodge City a large supply of water not rising in the wells is found at about the level of the Arkansas River or a little above it. As the country is high, the wells are deep. The profile seems to show a rise in the water-bearing stratum near the south end, but this is misleading. It is caused by the westing of the line, the water rising to the west nearly as fast as the country.

The Meade County artesian basin is of very limited extent. It lies in the immediate valley of Crooked Creek, a stream having a very small perennial flow. The basin is about 12 miles long north and south, and 5 miles wide east and west. In December, 1890, there were in this area between 85 and 100 wells flowing an average of about 15 gallons per minute each under a very light pressure. They are all 2-inch wells and vary in depth from 57 feet to 220 feet. This variation is not due to surface elevation nor to location. Wells 400 or 500 feet apart will vary as much as 100 feet in depth and one may flow three to five times as much as the other. The material in which the water is found seems to regulate the amount of flow. In the weaker wells the water-bearing material is very fine sand, filling up the pipes, as noted in well 173, at Santa Fe, Kans., while the stronger wells get their water from coarse gravel. The attached sketch (first published in your progress report last January) offers a probable explanation of the varying depth of the wells. The water is soft and pleasant to the taste. Increasing the wells does not seem to decrease the flow.

As to the source of this water, the average elevation of the basin is about 2,470 feet above sea level. The elevation of the Arkansas at Cimarron north of the basin is 2,620. This shows a fall of 150 feet in the surface in 30 miles, or 5 feet to the mile. As the fall of the Arkansas along here is about 7 feet to the mile, if the water came from the river northwest, it would be under a still greater head, so that, so far as elevations are concerned, it is possible for the water to come from the Arkansas. The country is said to be a low rolling prairie giving no surface indications of rock in place or other hard strata so near the surface as to prevent the southward filtration of the river water.

GREAT BEND LINE.

(See Appendix No. 12.)

The most easterly line on the Arkansas drainage crosses the river at Great Bend. This line runs from Smoky Hill River south through Hoisington, Great Bend, and St. John, to a point near Inka, Kans., and is 73 miles long. Owing to the detour to the north of the Arkansas at Great Bend, the south end of this line is directly east of Dodge City. It would probably have been more useful had it been carried about 20 miles farther south.

On the 20 miles of the line north of Hoisington water is very scarce. What little is found seeps in from clay on top of shale. Many dry holes have been put down. Only one well (No. 144) goes down any distance into the shale. It found a strong vein of salty water in 10 feet of sand and gravel 180 feet below the surface of the shale. The water rose 70 feet in the well and can not be lowered by windmill pumping.

At Hoisington well 138 was put down by the Missouri Pacific Railroad for engine use. It is 16 feet in diameter and reached water in sand mixed with clay. It furnishes 90,000 gallons per day of water drawn from that of Blood Creek Valley just to the south. This valley is 50 feet lower than the Arkansas at Great Bend, 8 miles south of it, but the bluff to the south of Blood Creek rises 100 feet above it and is soft sandstone nearly to the top.

A deep hole in the valley near Great Bend reached nothing harder than clay marl at a depth of 200 feet.

South of Great Bend the country is slightly rolling and sandy, being quite so at the south end. Water is found in large quantities at varying depths, but near the surface and in sand and gravel. The general level of the water in the wells examined is considerably above the river, but the level varies a good deal in contiguous wells, showing no uniform stratum.

The water in well 134 was struck in gravel under clay marl at a point 49 feet below the bed of the Arkansas River a mile and a quarter north of it. The water rose 55 feet in the well, or to a point 6 feet above the bed of the Arkansas. The river goes dry here at some seasons, and the water surface in the sand gets considerably below the bed of the stream. In December, 1890, it was 3 feet down to water, so that the water in this well, but little more than a mile away, was 9 feet above the river water.

Near the south end of the line the water-bearing stratum becomes more regular and dips to the south 4 feet to the mile, although the country is rising. The water is in sand under clay or cemented gravel and does not rise in the wells.

This completes the description of the several lines. The Frenchman, Big Spring, North Platte, Lexington, and Garden City lines come nearest to showing proof of the underflow theory. While it is probably true that the sheet water on the south end of the Platte and Lexington lines is fed by the Platte and on the south end of the Garden City and Dodge City lines by the Arkansas, the north end of these lines and the Frenchman and Big Spring lines clearly indicate that their sheet water is derived from local drainage, and instead of drawing on the mountain streams reënforces them.

Yours truly,

W. W. FOLLETT.

Col. E. S. NETTLETON,
Chief Engineer, U. S. Department of Agriculture.

THE NORTON, OR ONE HUNDREDTH MERIDIAN LINE.

(Appendix No. 13.)

This line was surveyed for the purpose of making a continuous examination of the water-bearing strata from the Platte to the Arkansas River. The line does not quite connect with the Lexington line, and is a short distance to the west of it. As will be seen by the profile there is no uniformity of position of the water-bearing stratum, the water line following quite closely the contour of the surface of the country. The wells along this line generally furnish water sufficient for domestic use and for stock purposes; in some instances 400 to 500 head are supplied from a single well. In several localities water was not found at all in some wells, while in others in the same neighborhood a very limited supply was found. This is generally the case where no sand or gravel was penetrated, and where the sand rock was absent. The lack of surface water in the large drainage channels like the Solomon, Saline, Smoky Hill, and Pawnee, was very noticeable. Many of the tributaries of these streams, with very much smaller drainage areas compared with those of the main streams, were carrying more water than any one of the above-named rivers. The water in these smaller tributaries is supplied by small springs which are generally found on the north side of the creek valleys, and issuing at the lower base of the sand rock when it was underlaid by an impervious rock.

In the immediate valleys of some of the creeks and so-called larger rivers are deposits of sand and gravel which undoubtedly carry more or less water; but the indications are that no great amount of water for irrigation can be obtained in these, especially when long intervals occur when these water-holding-sands are not reënforced by a surface flow.

This profile and some of the others show that the Platte and Arkansas rivers are higher than some of the drainage channels that lie between these rivers. Deep borings in the immediate valleys of both the Platte and Arkansas are reported to have been made without reaching bed rock, passing through sand and gravel the whole distance. This would indicate that these rivers have been gradually raised by the filling up of their deeply eroded cañons with sand and gravel brought down from above until their surface is, at the present time, almost on a level with their rock-bound sides. The plains streams lying between these rivers have not been filled up to the same extent, hence their difference in elevation.

UNDERFLOW AND IRRIGATION PROBLEMS WITHIN NEBRASKA AND KANSAS.

The Platte River traverses the entire length of Nebraska, and the Arkansas enters Kansas near the southwest corner of the State and passes out of it into the Indian Territory at the ninety-seventh meridian, or the eastern limit of this investigation. These rivers have their sources in Colorado and Wyoming, where they receive nearly the whole of their perennial water supply. The appropriation of the waters of the South Platte and the Arkansas has been already made by ditches and canals in Colorado under the constitution and laws of that State, to an extent that little water is left for either Kansas or Nebraska, except during the short period of the annual and storm-water floods. In both Nebraska and Kansas irrigation canals have been constructed, taking water out of these rivers, which antedate many of the large canals in Colorado, hence the possibility of a conflict of rights of an interstate character, and until these rights are adjudicated the surplus waters of the Platte and Arkansas rivers can hardly be depended on for irrigation purposes. Aside from the use of the water of the larger streams diverted by ordinary ditches and canals, the various methods of irrigation available for this country are about as follows:

(1) The use of subterranean water obtained by open subflow ditches.

(2) The use of subterranean waters raised a few feet by mechanical means.

(3) The use of the small perennial flow of the plains streams.

(4) The storage and immediate use of storm waters.

(5) The use of the flow of artesian wells.

Fortunately, for the benefit and protection of the irrigation development in the valleys of these rivers in western Nebraska and Kansas, there is a deposit of sand and gravel of considerable width and of unknown depth that is charged with water; just how much is available that can be utilized for irrigation purposes remains to be proved by actual development. The only practical tests of the quantity that can be taken out by sub-canal has been made at Dodge City and Hartland. A similar attempt is being made on the Platte River near Ogallala, Nebr. Other projects of the same kind in the Platte and Arkansas valleys are contemplated.

The amount of water obtained by the two sub-canals at Dodge City and Hartland is 15 cubic feet per second for each mile in length of the excavation that is made, 6 feet below the water line. It is found that the width of the canal has but little effect on the amount of water percolating into it; the depth and length are the controlling factors, other conditions being equal.

These sub-canals are simply drainage channels extended up and alongside of the river beds until the bottom of the channel has reached about 6 feet below the water line then the channel is given the same grade as the river and extended as far upstream as circumstances will admit, or until the desired amount of water is obtained. When the subcanal is made by removing the material in the ordinary way by scrapers, 6 feet deep below the water line seems to be the most economical depth for the excavation. Estimates from observations made of the inflow into channels cut to a greater depth show that it is about in proportion to the square of the depth. This estimate is verified by a deep excavation made on the South Platte, 25 miles southwest from Denver, where a company has put in a sub-conduit near the bed of the river, which is

18 feet below the water line. In 700 feet of this subconduit there is obtained 9,000,000 gallons each twenty-four hours, or at the rate of 153 cubic feet per second for a mile of such conduit. This shows about ten times the quantity obtained from a sub-channel 6 feet deep, which, if the above rule was applied, would be only nine times as great, or 135 cubic feet.

In answer to inquiries regarding the change (if any) in the amount of the flow of the sub-canal near Dodge City, which is the first attempt on a large scale to obtain water for irrigation purposes, Mr. G. G. Gilbert, one of the proprietors, writes, under date of November 6, 1891:

> The first attempt we made here to obtain water from the underflow was on a ditch known as the South Dodge Canal, where we last year excavated a ditch or gathering channel parallel to the Arkansas River, with the general result that for each mile of this gathering channel we obtained a flow of about 15 cubic feet of water per second. This flow has been pretty steadily maintained all this year, and we do not consider that the supply has either increased or diminished, nor do we find that the quantity of water running in the river has any effect whatever on the water which, percolating through the ground 6 feet below the river bed, finds its way into our gathering channel.
>
> Seeing the results which attended our works at the South Dodge Canal, we this spring began to carry out similar work at the head of the main canal, which, commencing near Ingalls, has a total length of 96 miles.
>
> We commenced this work on the same principle adopted at South Dodge, viz, excavating a canal or gathering channel, which, by following an inclination flatter than that of the river itself, gradually attains a depth of about 6 feet below the river bed.
>
> We carried on this channel for about 2 miles and obtained a very fair supply of water from it, quite as large, or indeed somewhat larger in proportion than we had at South Dodge. We find, however, that in order to obtain all the water we require we should have to carry on the gathering channel for some miles, and, looking at the expense of maintaining this work, we have come to the conclusion to adopt a different system.
>
> We have, therefore, by means of a centrifugal sand pump, excavated what we may call a gathering well, about 500 feet long and 8 feet deep (below the bed of the river), and have placed two powerful 15-inch centrifugal pumps to lift the water out of this well into our canal.
>
> We find it will be impossible to pump the water out of the well, whatever pumping power we may supply, and that we have therefore an inexhaustible supply in this way, which only requires to be lifted up about 5 feet.
>
> These pumps have only been running for two days, but nothing can be more satisfactory than the results they give.
>
> Generally, we may say that our confidence in obtaining an unlimited supply of water from what is known as the underflow is unabated, and when the conditions are such as to afford this supply, as they do in the Arkansas Valley, this system may be adopted with certainty of success.

There is not sufficient data obtainable upon which to form a definite opinion regarding the nearest distance these subcanals can approach each other without one interfering with the inflow of the other. It is claimed they can lap each other; that is, one can be started out opposite the lower end of the one above, or where the grade of the upper one is reduced in order to bring the water to the surface. If this be true, other sub-canals can be put in every 2 or 3 miles on each side of river channels like the Arkansas and Platte, providing there is sufficient water in the sands of the valley to furnish the necessary supply.

The investigation and discussion of the problems for utilizing the surface waters of the plains streams and the storage of storm waters do not belong properly to this inquiry, hence we will only briefly refer to them.

In many portions of the semi-arid country may be found small streams of water that have their origin in a small spring or wet piece of ground, and during their course for a short distance, and sometimes for a few miles, they are gradually reënforced by spring or seepage water until they become large enough to be of considerable value for irrigation purposes. Finally these creeks reach a point where instead of growing larger they begin to diminish in volume until the water entirely disappears. There are hundreds of this class of streams, which not only carry a constant supply through the whole season, but during a part of the year the flow is greatly increased by the drainage into them of surface water. These streams afford sufficient water, if properly conserved, to irrigate many thousands of acres in the narrow valleys bordering these water courses, which can be done at a very slight cost per acre, and on this account a great many farmers have already begun to irrigate in a small way, and have been successful in their attempts.

A large part of the whole country examined affords opportunities for the storage of large amounts of water in natural basins, but it is not possible to make any practical use of a majority of them for irrigation purposes: First, because they are so much below the general surface of the country that the water they would hold can not be taken out; second, there is not sufficient surface water to be found that can be turned into them. The storage and utilization of the water for irrigation purposes that falls on the surface of the great plains regions is greatly overestimated by many people.

A very small fraction of the rainfall on the plains regions can be conserved by means of storage reservoirs, on account of the small annual precipitation, the comparatively level character of the surface, and the deep and absorbing quality of the soil. Still, it is possible to do something in many small ways in holding back the flood waters of some of the larger streams and the strong waters that flow down the smaller channels for a few hours, but this will need to be done in the immediate vicinity and in the deep channels of these streams.

The presence of underground water is noticeable over most of the country wherever wells have reached sand, gravel, or quicksand overlying some impervious material. Instances where water is not found at all are rare. One reason for this is, that but comparatively few attempts have been made in districts where surface signs are unfavorable for obtaining water without considerable expense, as is the case in a section of country where the soil is clay of great thickness, with a surface having considerable slope from which the water rapidly runs off. If such a locality lies a few hundred feet above the surface of a running stream, the chances are that water will not be found until that level is reached. In many places on the plains where water was not at first found, or, if found, it was in very small quantity, in years afterwards the same locality afforded a supply sufficient for domestic use, with indications that it is increasing in quantity. This is accounted for very readily in an irrigated country, where a portion of the water supplied artificially is absorbed and travels downward until arrested by an impervious stratum of clay or rock. We can account for its first appearance, or for its increase of quantity, in a nonirrigated district, only by the fact that breaking up the original surface by the plow puts the soil in a condition to absorb a large portion of the rains that before ran off into storm-water channels, which is quickly carried away.

It is a noticeable fact in an irrigated country that natural depressions in the surface of the ground, which never contained water prior to irrigation, are beginning to fill with water, even where no surface water from irrigation reaches them, nor can any springs or seepage be observed. These basins have been steadily filling, without any apparent water supply, from the results of irrigation. This is accounted for by the partial saturation of the earth around and under these basins to such an extent that it retards the percolation of the natural precipitation, which permits a larger run off of the catchment area of the basin. The opposite effect has been observed in lakes that lie in a country where no irrigation is practiced, but where the surface has been broken by the plow; that is, lakes that before the country around them had been cultivated received drainage water sufficient to balance the loss by evaporation and infiltration, but since the surrounding watershed has been cultivated these lakes are gradually drying up. It is claimed that this is not due to a decrease in the annual rainfall, as these observations have extended throughout a term of years, and in a country where the rainfall is claimed to have increased. The probable cause for this is the same that produced the increased amount of underground water as cited above, where cultivation increased the absorbing capacity of the soil and decreased the run-off, which in this case reduces the amount drained into the lakes.

The annual rainfall is thought to be more evenly distributed than formerly in the settled portions of the country. Heavy rainfalls and cloud bursts are less frequent than formerly. The settling and cultivation of the country tends to modify the climate and produce a more equable distribution of temperature and precipitation. I think this is generally conceded to be the case in portions of Kansas and Nebraska.

This being true as regards precipitation, then we have less water than formerly rushing off the surface of the ground into lakes and creeks. The economic value of the effect of these phenomena is but little compared with that which produces the cause.

There are other matters reported concerning the underground water that have come to our notice which in themselves are more curious than valuable. It is reported that there are several dug and bored wells in western Kansas and Nebraska and in eastern Colorado that seem to have some connection with the atmosphere in some of its peculiar conditions. Some are affected in one way and some in another by the same prime causes.

The blowing wells, as they are called, are so common in this part of the country as to cease to be a wonder to the people, though no one attempts to explain these freaks, except that a northwest wind is thought to have something to do with them. The most common of these strange occurrences seems to be the emitting of air from the wells just before and during a storm from the northwest. The statements made to us are from reliable men who have personally observed these phenomena.

Mr. Mark Burke, county surveyor of Perkins County, Nebr., writes in answer to some inquiries about these wells, and says:

> I hurriedly submit all the information I have at present in regard to the phenomena of "Blowing wells." Had I known that it would be of any service to the artesian investigation I would have been more diligent in my researches.
>
> In addition to observations of the influx and efflux of air and the attendant phenomena in a few particular wells in this vicinity, I send you a chart of the direction of the currents of air in the St. Elmo well at Grant, compared with the atmospheric pressure as indicated by the barometer at North Platte, Nebr., through part of the month of February, 1891, and I am satisfied that the phenomenon of "blowing" and "sucking," as it is usually termed, is common to nearly if not all the deep wells of the table-land in this and adjoining counties. Though I have made frequent inquiries in different parts of this and adjoining States, I have not been able to learn of the existence of such wells at a greater distance than 40 miles from here, though it is probable that close observation would show that they exist, but with currents of less velocity. The great Cave of the Winds, in Wyoming, manifests a similar kind of phenomenon.
>
> The well which supplies Sayers & Walker's livery barn in Grant is 3 feet in diameter and 160 feet deep. It was dug during very cold weather in the winter of 1887-'88. Three strata of dry gravel was passed through 60, 80, and 100 feet from the surface. The

strata are 10, 25, and 40 feet thick, respectively. On reaching each of these strata an ascending or descending current of air was noticed, which was sometimes reversed before the stratum was passed through. After the third vein of gravel was reached a downward current prevailed, and during the succeeding night the moist bottom of the partially completed well was frozen to the depth of 3 inches. This was at the depth of 110 feet. The water in the 2-inch pipe through which it is pumped was, during another cold spell after the well had been completed, frozen 96 feet below the surface of the ground, causing the pipe to burst.

John A. Miles's well, on sec. 9, T. 9, R. 38, is 3 feet in diameter and 138 feet deep. There is usually not more than 10 feet of water in this well, but at three different times last spring the water raised, filling the well and flowing out over the surface of the ground. Mr. Miles was unable to tell how long the overflow lasted, but said he had to dig a small trench to lead the water away. In other wells in that neighborhood, where water is raised with a bucket attached to a rope, it does not require close observation to prove that there is a fluctuation in the depth of the water, and it is confidently asserted by the owners of these wells that there is more water in the wells when the wind is from the north or northwest than from other points.

The water in the well on the NE. ¼ of sec. 28, T. 10, R. 35, is reported by Martin Cosgriff, of Elsie, Nebr., to have been so hot at different times that he could not endure to hold his hand in the water. He said he was willing to swear to the truth of this statement.

The accompanying diagram is a copy of the one referred to by Mr. Burke, who defines the term "moderate" as being a current up or down the well that was accompanied by a roaring sound and a current sufficiently strong to be plainly felt by the hand. The "strong" current was accompanied by a hissing sound, and was strong enough to throw an opened newspaper out of the well with considerable velocity.

Mr. R. I. Smith, of Winona, Kans., writes:

> I have a 6-inch bored well in my door yard, 135 feet deep, with 8 feet of water. Over a year ago I noticed that at times a strong current of air came out of the openings around the pumpstock, and by observation find it to be an excellent barometer, as it blows from six to twenty hours preceding a storm. I have placed a brass whistle in the space, which at times can be heard a quarter of a mile. The harder and longer it blows the more intense the coming storm will be. A peculiarity of it is the fact that, after the storm, it takes back the wind.

Mr. Smith asks for a scientific solution of the phenomenon.

MOVEMENT OF UNDERFLOW IN RIVER VALLEYS.

Comparatively little is known concerning the rate or velocity of the flow of underground water. That which prevents water from running underground as rapidly as it does on the top, when the grades are equal, is the friction of the water in motion through the soil or water which comes in contact. The more open and porous the material, the more readily will water respond to the force of gravity, and *vice versa*, until the friction is so great in the material under certain conditions that water will not of its own gravity or weight pass through the material, or can not be easily forced through.

The character of the material in which the underground water exists is an important and controlling factor in the solution of the question as to the extent to which the subterranean waters can be applied for irrigation purposes. However bountiful the supply may be, unless it is susceptible of being transported underground, it will be of little use for the purposes under consideration. It is the common opinion with those who have given the subject but little attention that the underground waters have a rate of movement corresponding with the slope of the country, and which would be quite marked if it was possible to obtain its velocity, and would approach that of a surface running stream. We often hear statements made of a stream of water running from one side of a well so rapidly as to carry a float quickly to the other side;

also, that the water comes in from the uphill side. More careful observations show that these currents are caused by the rapid flow into the well when it has been pumped down, but when the water reaches its full height they disappear. The results obtained from scientific investigations of the rate of the movement of underground waters are not of a very definite character, and more than an approximate estimate can not now be given of this important factor in the question under consideration. Some of the French engineers place the rate of movement of underground water in the river valleys at one mile in a year, or a little over 14 feet per day, or one-eighth of an inch in a minute. This seems like a very slight velocity, but from my own observations of the travel of seepage water along a highly inclined surface, of an intervening but impervious material, I am inclined not to doubt the statement. It was our aim to make some experiments for the purpose of determining the travel of water in some of the river valleys in Kansas and Nebraska, but after a couple of attempts in a hasty and crude way, without any except negative results, we concluded we could not spare the time that would be required to obtain reliable data.

The two unsuccessful attempts, however, were not without some reward. One of these was made on a little island, or sand bar, in the channel of the Rio Grande, near El Paso, Tex. This sand bar was but slightly above the surface of the water in the river. In fact, it had been under water until a few days prior to our attempted test. The plan was to sink holes in the sand a little below the water line, with the expectation that the water would rise in them to the same level as the river surface; then we were to note the interval of time it took a colored fluid, of the same density as water, to travel from one hole to the next one further down the stream; but even on this island, surrounded by water, and composed of the same material to all appearance as the river bed and its banks, as well as the whole country bordering on the river channel, we did not succeed in finding water at 3 feet below the surface of the river, which was within a foot or so of the pit, and no water came into these holes within the next twenty-four hours. This proves that the silt that comes down with the water of that river has a tendency to seal up its channel, and but little loss of water by infiltration into the channel sands can occur. Another evidence of the sealing effect of the silted waters of the Rio Grande was observed on the Mexican side. Two years ago the main current and deepest water was on that side of the river, and as a result the channel was gradually encroaching on the old city of Juarez, when the Mexican Government took steps to protect the bank, which was done by building a brush and rock jetty out into the river, and extending it down stream parallel with the banks. This jetty was 150 feet in some places out into the river channel. Between the jetty and the bank was the deep channel of the river. The jetties practically divided the river from its old bed, leaving a pool of deep water. This pool of water was in February last almost dried up simply by evaporation. Within 100 feet of it was the river whose surface was fully 8 feet above the surface of the water in the pool. These facts are important in the consideration of the question of the amount of underground water in a valley like the Rio Grande, that is available for irrigation purposes. Upon following up the question of underground waters in the vicinity, I found the best wells for domestic purposes and those furnishing the most water were usually those away from the river and nearer the outer side of the valley, where the water is found in coarser material and which possibly comes from the higher country.

The other attempt to determine the velocity of the underflow was made in the bed of Cherry Creek, near Denver, Colo. The bed of this creek is composed of coarse sand and gravel. The grade or slope of the bed is about 30 feet per mile. At the place where the experiment was made the sandy bed is wide and flat, and at the time there was a little water running on the surface, and when a hole was made in the sands a few inches deep it would instantly fill with water to a level with that running on the surface. To all appearances it would be almost impossible to dip the water out of an opening 2 feet cube any faster than it would run in. The plan proposed for obtaining the velocity here was to dig a small pit a little below the surface of the water, then downstream from this dig a short trench 5 feet from the pit, and 5 feet still lower down dig another trench, and so on, having a line of trenches 5 feet apart across the supposed line of underground flow. This being done, a strong solution of aniline dyes, purple, was put in the water in the pit with the expectation of seeing it appear in an hour or so in the first trench, but twenty-four hours failed to show any colors even in the first trench. Apparently all the coloring matter remained in solution in the pit. The result was so contrary to our anticipation and so disappointing all around, and on account of pressing engagements elsewhere we did not pursue the investigation as we should have done to have settled the question conclusively whether or not there was any perceptible velocity or whether the means used were at fault.

In nearly all the valleys of the large rivers, especially some distance from the mountains, there are deep deposits of river drift. These drift deposits lie in a rock-bound, troughlike channel and are in some places several hundred feet deep and from 10 to 20 miles wide, as is the case in the valleys of the Platte and Arkansas rivers. Then in other places in the same valleys, the rock sides and bottom of the channel are so contracted as to collect the surface and underground waters into a narrow valley, with this rock bed close to the surface. At such places there is usually more water found running on the surface at times of low water in the rivers than where the deposits are wide and deep. The coarser the gravel and sand deposits are, the more water comes to the surface in such places. This is the case with the Rio Grande at El Paso. Other conditions change the result.

The drift deposits in the valley in that river for several hundred miles above El Paso are fine sand and other material which does not admit of water passing freely through it. At El Paso the river passes through a narrow channel or gorge in the mountains, which is rock-bound, so that the whole volume of the underflow must come to the surface. The underflow is so small at this place that when the river dries up, as it frequently does, there is no running water, no more than in the river above, where the valley is 5 or 6 miles wide and where the river deposits are probably over 100 feet deep.

In the valleys of the Platte and Arkansas, where the bed rock brings all the underflow to the surface, water flows at these places when the surface stream above is dried up, but not to the extent that would be expected if the underflow was as great as many claim it to be. This fact is another indication that the rate of movement of the underground waters is comparatively very slow. Not having made careful measurements of the increase in the volume of the surface flow at such places, we have not sufficient data from which to verify the deductions of the French engineers that the velocity of the underflow is 1 mile a year, but from personal observations made years ago in the Platte River Valley, I am inclined to think that this estimate is too low for the underground flow of the Platte River, or any river whose bed is composed of coarse sand and gravel. The volume of water that would pass through the section of a river deposit 1 mile wide and 10 feet deep would be only 2.6 cubic feet per second, if the movement was only 1 mile a year, that is, assuming that three-tenths of the bulk of the underground mass was water. While this rate may be too low for the Platte River, it is undoubtedly too high for the Rio Grande, and possibly it would not be much out of the way for the Arkansas River below Lamar, Colo., as that river is a silt-carrying stream and the river-bed deposits are largely made up of silted sand and clay, with an inclination of from 4 to 7 feet per mile.

The efficiency of different soils and formations for transmitting water freely is very noticeable in the operations of the sub-canals for leading off the underflow water. The proprietors of the South Dodge (Kansas) sub-canal say it makes but little difference in the flow of their sub-canal whether there is a flood height of water in the river or whether it is dry. This sub-canal is excavated about 6 feet below the low-water level of the river and runs alongside of the river for 2 miles and is in some places 500 feet from it.

The engineer at the southwestern canal, which is supplied in part from the sub-canal near Hartland, Kans., says in regard to the flow of the sub-canal:

> This stream has been constantly running for a year at highest stage of water in the river, when it was 7 to 9 feet higher than the water in the ditch for a period of two months and for 1,000 feet, running within 100 feet of the river, the ditch increased its flow about one-third, which shows that water is substantially obtained from the underflow.

In this instance, as in the one at Dodge City, the lower stratum of sand is the best conductor; the upper stratum probably contains more silted material. In the South Platte River, near the mountains, where the channel bed is composed of coarse sand and gravel, with but little silt or clay in the material, the engineer in charge of the construction of the sub-conduit says a rise of 6 inches in the river increases the supply more than 100 per cent. In this instance the upper stratum is as good and perhaps a better conductor than the lower. The character of the material here being coarser than that in the Arkansas River, it responds more readily to the influence of the surface supply, which is an indication of a greater capacity to transmit water more rapidly.

The amount and rate of the movement of the subterranean water existing in the drift formation of the great plains are undoubtedly very much less than in the river valleys, like those of the Arkansas and Platte. In these valleys there is a deep deposit of material, composed generally of sand and fine gravel, on top of which is a broad and constantly running stream of water, coursing through the whole length of these valley deposits (except, it may be, for a few weeks at a time), affording a surface supply to maintain a complete saturation to the same level of the water in the river.

Outside of these river valleys water is usually found only in comparatively thin strata of sand and sandy material, sometimes mixed with a little gravel and often with a good deal of clay. These strata are usually underlaid and sometimes are overlaid with impervious material, and the water-holding strata, instead of being continuous as in the valleys, are often pinched out, rendering it impossible for water to travel in direct lines for long distances.

It will be observed by referring to the profiles that outside of the river valleys the line of underground water, or saturation, generally conforms somewhat to the surface of the country. The slope of this line is frequently quite abrupt towards the drainage channels of the surface water. If the underground water existed in large quantities and in materials which would allow it to flow freely, we would naturally suppose it would respond readily to the laws of gravitation and come to the surface in the form of springs along the sides of the deeply eroded channels where these water-holding materials outcrop or come very near the surface, but this is not the case, except in a very few places, the most notable of which are on the head waters of the Republican River, where considerable underground water comes to the surface, which occurrence will be noted by the geologist.

Assuming that the underground water outside of the river valleys lies above the surface of the running streams (as it generally does), it will be apparent that water found in the drift of the Great Plains can not be supplied from the surface or underground water of these streams.

If this be true, we then have the water falling on the surface of the country in the form of rain and snow as the only source of supply. Just how much of this is available to compensate for the draft which would be made if irrigation from this source was resorted to, we do not undertake to estimate. It must be remembered that the annual precipitation on this region is small and the evaporation quite large, and, after taking into account what runs off in storm-water channels, the amount that finds its way into the earth below, where no loss can occur from evaporation, on the average must be very small, and the area capable of being irrigated will, without doubt, be far less than many have estimated. Still there is sufficient water at reasonable depths in many places that can be made to serve a few acres under proper husbandry, where the net profits, taking one year with another, will be greater than farming in the ordinary way on much larger areas, especially in the semiarid regions.

RAISING WATER BY MECHANICAL APPLIANCES.

The value of the underground water supply for irrigation purposes depends upon its depth from the surface, the quantity that can be obtained, and the permanency of the supply. If it is too deep the cost of raising it will preclude its use. If it is in so small quantities that it must accumulate little by little, and be stored away, this will likely prove too expensive for general farming.

The outlay necessary for obtaining a small supply is often as great as that of a larger one. The maximum amount that is practicable to expend for obtaining water for irrigation purposes is generally governed by the use to which it is put. For instance, one man can afford to pay or expend $25 per acre foot* for water to irrigate land on which are grown high-priced fruits and vegetables, while another can hardly afford $1.50 per acre foot for water for common farming purposes. The same can be said in regard to the height to which it is practicable to raise water. Ten feet might be the highest that is practicable to raise water for ordinary farming purposes, while for intense agricultural and horticultural purposes 50, 100, or even 150 feet may be admissible. The cost for power to raise water increases as the vertical distance increases that the water has to be raised. Raising water to the surface for irrigation by mechanical appliances, propelled by wind, man, horse, or steam power, is not by any means impracticable so far as the cost is concerned, even for agricultural purposes. Raising water by these means is coming into use in our own country, as there are now quite large areas of land irrigated from water raised to the surface by various mechanical means, specially in the southwestern portion of the arid country.

---

*An acre foot is a convenient unit for designating a given quantity of water, as it combines both units for linear and land measurements. It is equal to a volume of water that will cover 1 acre of land 1 foot deep. Thus, the expression of 3¼ acre feet means 3¼ acres 1 foot deep, or an equivalent quantify would be 1 acre 3¼ feet deep.

To show what has been done in other countries by this method of irrigation, it is stated that in 1864 there were in Central and Lower Egypt 50,000 pumps and water wheels in use. These were driven by 200,000 oxen and 4,500,000 acres were irrigated. The wells are shallow and the pumps and appliances are of the crudest kind. The average cost of a well and pump is $150. In Lower Egypt at one time there were 2,000 steam pumps used for raising water, where the cost of coal was from $10 to $20 per ton. The annual cash rent per acre was from $2 to $5. The crops raised were cotton and rice. If the rental was paid in kind it was one-fifth of the cotton and one-fourth of the rice.

There are many places where large amounts of water exist at depths too great to be reached by sub-canals, but which can be brought to the surface by mechanical means. Carefully made calculations show that it is practicable to raise water for general irrigation a few feet by steam pumps or animal power. It can be put on the land at a cost which will exceed but little if any the cost of water obtained from the more expensive irrigation canals. One great drawback to the adoption of this method in new countries is the first cost of the plant, but as the country grows older and richer a considerable amount of land will be irrigated in this way.

The average expense of raising water by high duty steam pumping plants in twenty-four cities in the United States shows that it costs $3.55 to raise an acre foot of water 100 feet high. This includes cost of fuel, labor, oil, and ordinary repairs, but does not include interest on cost of plant, nor the natural wear and tear of the machinery.

There are records of some pumping plants that will raise an acre foot 100 feet high at a cost of $2.25. These plants are of course expensive ones, which can not be avoided where so high duty is obtained. Many of the ordinary and low-priced steam plants will run up the cost to $5 or $8 per acre foot. The cost of raising water by vacuum pumps similar to the Hoffer or Greeley pump is not less than at the rate of $12 per acre foot lifted 100 feet. This form of pump will raise water not to exceed 30 feet, depending on the elevation. A modified form of this pump using the direct pressure of the steam to force the water above the vacuum limit is used when it is required to raise water to a greater height. These forms of pumps are inexpensive, but the duty is very low. A great many of them have been in use during the past two seasons, but as a general thing are considered expensive contrivances for raising water, only suitable for lifting water a few feet for gardening and like purposes.

For gardening and horticultural purposes considerable irrigation can be done by water pumped by wind power from wells not too deep. Water pumped in this way should flow into a reservoir and be used in large quantities. In this way pumping can go on continuously whenever the wind is blowing, night or day, and the work of irrigation can be done at the times when the crops are in need of it. The area that can be covered by a single well may be small, but the number of wells can be indefinitely increased whenever the water supply will admit.

We noticed two small irrigating enterprises in Kansas where the water was raised by windmills. In one a 10-foot windmill was used to raise the water 10 feet which was run into a storage reservoir 40 feet wide, 60 feet long, and 3 feet deep. The reservoir was made on the top of the ground with embankment of earth; with an 18-mile wind the mill would fill the reservoir twice each twenty-four hours. The pump used was a 5-inch Gause pump, which was attached to four drive wells which reached water 7 feet from the surface, raising it to the top of the reservoir, making the total lift 10 feet.

The water was made to serve a 4-acre vegetable garden and small fruits. The cash outlay was $135. The products of the garden sold for $400, besides what was consumed by the family, and $100 worth were unsold. The expenses for oil and repairs for the season was 80 cents.

The other was on a little larger scale, having a 16-foot windmill which raised the water about 14 feet, which is stored in a reservoir 55 feet wide, 178 feet long, and 4 feet deep.

An 8-inch Gause pump is used and with a fair wind will pump 16 inches depth of water into the reservoir, or about one-third of an acre foot. The cost of this plant was $500. Seven acres of garden vegetables were irrigated from this supply. The proprietor estimates 12 acres of fruit trees can be irrigated besides a large amount of vegetables.

These small irrigation plants and the beneficial results accruing from them are illustrations of what can be done in thousands of other places in the arid and semiarid country, when subterranean water can be found near the surface. The net profits from these small areas in high cultivation under irrigation exceed those of a square mile two years out of five in many places where only the natural rainfall is to be depended upon.

ARTESIAN WELLS STATISTICS.

The following list of artesian wells does not include all of the deep bores made in the Dakota basin. Several are omitted on account of their isolated condition, which would have required more time to inspect than we had at our disposal. There are also quite a number that have been completed since the close of the fieldwork, and others in the process of completion, which do not appear in the list. The ninety wells noticed do not by any means represent the whole number of bores into the main artesian flow.

The investigation of the Dakota artesian wells during the past season includes a wider range of inquiry than was made in the spring of 1890. The stratigraphy of the rocks penetrated and the mechanical appliances used for conducting the flow to the surface have been made subjects of special inquiry. It is believed that the data furnished in the logs of the following list of wells, and in the illustration of the most important part of the data by profiles, will be of considerable value in the future extension and development of this great artesian basin.

In the tabulated list will be found the elevations above and below sea level of the rock strata and water courses, and the bottom of the bores. The exact points at which flows of water were found is not given, as the logs generally failed to note the depth, except to mention the stratum in which they were found. Therefore, we give the elevation of the top of the rock in which the flows are obtained. The investigations do not show as great uniformity in the position of the upper water courses or the main water-bearing rock as was first thought to exist, nor does there appear to be a general similarity in the character of the lower rocks. A part of these irregularities can be accounted for by the fact that these bores have been made by several different drillers. One driller may have an entirely different name than the other for a certain rock; besides, we find in many cases that no record of the strata passed through was made at this time, and we have been obliged to depend upon the memory of people for depths and the character and thickness of the rock formations.

The best method of casing wells is an important problem to be solved. The permanent seating of the casing, the proper lap, the proper protection against clogging up at the bottom, and the durability of the casing are all matters of vital importance to the life and success of the well. Failures on account of the noncompliance with some of the above requirements have already occurred in some wells, and others will sooner or later get out of order for like causes.

It is hoped that the partial record that we give of the manner in which artesian wells are cased will be of service in the future as a means of reference to methods to be avoided as well as those to be adopted.

Plankington well.—Located in Sec. 22, T. 103 N., R. 64 W., town of Plankington, county of Aurora, State of South Dakota. Owned by town of Plankington. Completed fall, 1890. Drilled by Gray Brothers, Milwaukee, Wis. Depth, 830 feet. Cost, $3,200, or $3.85 per foot. Flow, 225 gallons per minute. Pressure, 91 pounds per square inch when flow is shut off. Temperature of water, 62 degrees. Elevation above sea level, 1,521 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Black loam	3	3	Sandstone (water)	5	543
Yellow clay	223	226	Shales	197	740
Chalk	9	235	Sandstone (water)	5	745
Shale	303	538	Sioux Falls granite	85	830

The water from this well supplies the town with domestic water, which is quite hard, containing considerable gypsum. The upper vein was soft. When the flow is shut off the pressure quickly runs up to 50 pounds, and in three hours it reaches its maximum, 91 pounds per square inch. When allowed to flow freely very fine sand and gypsum comes up with the water. The casing is 3-inch and 4½-inch. The amount of casing in the well is not known, but the first flow is said to come up between the 3-inch and the 4½-inch, so it is quite certain that the 4½-inch stops short of the first flow, which is at 540 feet. There is probably about 745 feet of 3-inch casing in the well.

White Lake well.—Located in Sec. 14, T. 103 N., R. 66 W., town of White Lake, county of Aurora, State of South Dakota. Owned by town of White Lake. Completed fall, 1887. Drilled by Swan Brothers, Andover, S. Dak. Depth, 863 feet. Cost, $3,800, or $4.40 per foot. Flow, 150 gallons per minute. Pressure, 35 pounds per square inch when flow is shut off. Temperature of water, 64 degrees. Elevation above sea-level, 1,630 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Yellow clay	40	40	Blue shale	65	565
Blue clay	50	90	Hard lime and shale	15	580
Blue sandy clay	30	120	Blue shale (tough and sticky)	180	760
Blue shale	170	290	Sandstone (some water)	3	763
Black shale	30	320	Iron pyrites	3	766
Sandy shale	30	350	Blue shale	10	776
Gray shale	20	370	Shale and lime	57	[illegible]
Soapstone	100	470	Sandstone (flow)	6	[illegible]
Lime and iron pyrites	10	480	Sioux quartzite	12	[illegible]
Sandy shale	20	500			

The top of this well is 129 feet higher than the Plankington well, but the height to which the water will rise from the static pressure of the two wells is exactly the same, being 1,713 feet above sea level in each case. Like the Plankington well the bore reached the quartzite rock, which lies only 24 feet higher at White Lake, showing a dip to the east of 2 feet per mile. This well is cased with a single line of 4-inch casing 840 feet. The water is used for domestic and stock purposes, and is also used for irrigating 5 acres of land without the aid of a reservoir.

Collins well.—Located in Sec. 10, 110 N., R. 60 W., 2 miles south of Cavour, county of Beadle, State of South Dakota. Owned by township. Commenced June 24, 1891. Drilled by J. C. Weston, Huron, S. Dak. Elevation above sea level, 1,331 feet.

Hitchcock well.—Located in Sec. 4, T. 113 N., R. 63 W., town of Hitchcock, county of Beadle, State of South Dakota. Owned by town of Hitchcock. Commenced May, 1885. Completed August, 1885. Drilled by Gray Brothers, Milwaukee, Wis. Depth, 953 feet. Cost, $4,400, or $4.62 per foot. Flow, 1,240 gallons per minute. Pressure, 154 pounds per square inch when flow is shut off. Temperature of water, 70 degrees. Elevation above sea level, 1,239 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil and yellow clay	100	100	Sand rock (small flow)	4	928
Blue shale	350	450	Sand rock and sandy shale	22	950
Shales	470	920	Sand rock (flow)	3	953
Cap rock	4	924			

This well was put down to obtain a water supply for domestic and fire purposes, having a larger flow than is required to serve the town, a portion of which is used to drive a 45-barrel flour mill. The power developed takes the place of a 25-horse power steam engine. The water, after passing through the wheel, is used to irrigate 75 acres of land, without the aid of a reservoir. When the water from the well is not used for irrigation purposes it is allowed to run to waste. The well has flowed constantly for six years, with no change in the pressure or quantity. When the flow is shut off the pressure runs up quickly to 154 pounds. The outside casing, 4½ inches in diameter, is seated in blue shale rock 800 feet from the surface. Inside of this is 160 feet of 3½-inch casing, which laps on the lower end of the 4½-inch 40 feet, and extends down 920 feet, or within 33 feet of the bottom of the bore. The small flow at 926 feet was soft water and quite cold. The main flow at the bottom of the bore is much higher temperature.

City well.—Town of Huron, county of Beadle, State of South Dakota. Owned by water company. Completed in 1886. Drilled by Swan Brothers, Andover, S. Dak. Depth, 906 feet. Cost, $4,000, or $4.42 per foot. Flow, 1,668 gallons per minute. Pressure, 120 pounds per square inch when flow is shut off. Elevation above sea level, 1,251 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Yellow clay	13	13	Conglomerate sand, shale, etc.	51	601
Blue clay	76	89	Gray shale	101	702
Gray shale	151	240	Brown limestone, cap rock	10	712
Hard iron rock	3	243	White sand rock (flow)	50	762
Sand rock	5	247	Hard sand rock	10	772
Hard sand rock	2	249	White sand rock (flow)	25	827
Gray shale	175	424	Gray lime rock	55	[illegible]
Hard sand rock	10	434	Gray shale (caving)	4	[illegible]
Gray shale	15	449	Gray limestone (stopped)	10	[illegible]
Brown shale	101	550			

This well is one of the first wells put down in the Dakotas for municipal purposes. It has been constantly flowing for the past five years, except during a few weeks in 1890, when the casing had to be drawn to repair the lower section which had been destroyed by the corroding effects of the water on the iron. It is used for domestic and fire purposes, sprinkling lawns, and watering shrubbery, besides driving motors for power purposes, such as propelling printing presses, spice and coffee mills, etc. The well is cased with 6-inch casing to a depth of 712 feet.

Day-Harrison well.—Located in sec. 11, T. 110, R. 62, town of Huron, county of Beadle, State of South Dakota. Owned by F. T. Day. Commenced February 1, 1890. Completed May 1, 1890. Drilled by Roberts. Depth, 847 feet. Cost, $1,850, or $2.12 per foot. Flow, 496 gallons per minute. Pressure, 120 pounds per square inch when flow is shut off. Elevation above sea level, 1,306 feet.

No record was kept of the strata passed through while boring this well. It was put down for water for irrigation purposes. In the winter of 1890 and 1891 the water was allowed to flow promiscuously over the land and as a result some of the land was greatly over-irrigated, and was so wet that crops could not be put in until late in the spring. A system of irrigation ditches has been laid out on a farm of 320 acres, and the area to be placed under irrigation is being doubled by the construction of a 2-acre reservoir. This well is reported to have a variable flow during the spring months. Its flow increases until midsummer, then gradually diminishes, reaching its minimum during the winter. It is claimed that the flow varies with the rise and fall of the water in the Missouri River. This well is cased with 4-inch casing to the first flow.

Huron Mill well.—Located in sec. 36, T. 111 N. R. 62, town of Huron, county of Beadle, State of South Dakota. Owned by city of Huron. Commenced May 1, 1890. Completed September 1, 1890. Drilled by Howard, Holton Bros. Cost, $3,600. Flow, about 700 gallons per minute. Pressure, 106 pounds per square inch when flow is shut off. Elevation above sea level, 1,280 feet.

There was no record kept of the strata of this bore. The contractor reports that blue clay and soft shales were encountered on the way down to the first flow (500 feet), thence to the bottom where were soft strata of sand rock between the shales. No cap or hard rock was found. The well is reported to discharge about 700 gallons per minute, after the flow has been shut off for a day or so, but when opened and given a free discharge the flow rapidly diminishes. The well was put down to obtain water for power purposes, but on account of the diminished pressure and the quantity of water discharged when opened the well is a failure for that purpose. It is cased with 300 feet of 8-inch casing, 437 feet of 6-inch, and 104 feet of $3\frac{1}{16}$-inch casing. The contractor was inexperienced, and on account of bad management the bore and its appurtenances cost him $1,400 above the contract price.

Richards well.—Located in sec. 30, T. 112 N., R. 61 W., 7 miles north of Huron, county of Beadle, State of South Dakota. Owned by American Investment Company. Commenced October 15, 1890. Completed November 15, 1890. Drilled by Swan Bros., Andover, S. Dak. Depth, 917 feet. Cost, $3,668, or $4 per foot. Elevation above sea level, 1,300 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	1	1	Sand rock (first flow)	20	789
Yellow clay	14	15	Sandy lime	10	799
Blue clay	40	55	Sand rock (got most of water)	30	829
Sand and gravel	45	100	Lime rock	20	849
Soapstone	280	380	Sand rock (very little water)	20	869
Rotten lime and slate	20	400	Iron pyrites and lime	5	874
Soapstone	300	700	Sand rock (no water)	10	884
Iron pyrites	2	702	Rotten lime	16	900
Soapstone	60	762	Soapstone	10	910
Iron pyrites and lime cap rock	7	769	Iron pyrites and lime	7	917

Stopped in iron pyrites.

This well was put down for water supply for irrigating a farm of 480 acres, 300 of which were irrigated this year by aid of a 7-acre reservoir, whose holding capacity is about 35 acre feet. The water is quite clear and soft. The well is cased with 762 feet of 6-inch casing; 60 feet of 4½-inch casing is put in at the bottom, which laps 10 feet on the 6-inch casing. The lower end of the 4½-inch casing is perforated with ½-inch holes.

Risdon well.—Located in sec. 30, T. 111 N., R. 61 W., town of Huron, county of Beadle, State of South Dakota. Owned by A. H. Risdon. Completed March, 1891. Drilled by J. C. Weston, Huron, S. Dak. Depth, 960 feet. Flow, 2,250 gallons per minute. Pressure, 165 pounds per square inch when flow is shut off. Elevation above sea level, 1,290 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Ordinary clay and shale (to small flow at)		240	Shale	9	700
Rock and iron pyrites	5	245	White shale and sand rock (seventh flow)	3½	703½
Shale	215	460	Water-bearing rock	29½	733
Limestone (second flow)	50	510	Water mixed with white slate	117	850
Shelly lime (third flow)	2	512	Flint	20	870
Shale	88	600	Sand and slate	20	890
Sand and shells (fourth flow)	5	605	Very hard cap rock	12	902
Shale	35	640	Soft sand rock (flow)	33	935
Shelly lime (fifth flow)	1	641	Soft sand rock (heavy flow)	25	960
Shale	49	690			
Shelly lime (sixth flow)	1	691			

This bore was made for testing the presence of natural gas, which was supposed to exist inside of 2,000 feet from the surface, a party of gas-well operators from Findley, Ohio, having made a royalty contract for the land surrounding the well for this purpose. At 960 feet a strong flow of water was struck, which it is claimed rendered further drilling impossible with the appliances they had. It is reported when the lower vein was reached the upward flow was so strong as to lift and support the drilling tools which weighed over 2,000 pounds, thus preventing any further progress in drilling. Complications have arisen regarding the terms of the contract and ownership of the water, and the well has been practically shut down since drilling was stopped. This is one of the strongest flows in the James River basin, it being sufficient to develop at least 100-horse power, besides furnishing water sufficient to cover 90 acres with a 6-inch irrigation over twenty-four hours. This well is cased with 8-inch casing to 703½ feet. Inside of this is a string of 6-inch which reaches within 58 feet of the bottom of the bore. Owing to the prospective lawsuit over the ownership we are unable to get its cost.

Wolsey well.—Located in sec. 23, T. 111 N., R. 64 W., town of Wolsey, county of Beadle, State of South Dakota. Owned by town of Wolsey. Completed September, 1890. Drilled by Swan Bros., Andover, S. Dak. Depth, 930 feet. Flow, 390 gallons per minute. Pressure, 137 pounds per square inch when flow is shut off. Temperature of water, 76 degrees. Elevation above sea level, 1,348 feet.

Strata which are passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	1	1	Sand rock (flow)	20	828
Yellow clay	19	20	Lime rock	30	858
Blue clay	40	60	Sand rock (most of water)	20	878
Gray shale	154	214	Soapstone	15	893
Dark shale	276	490	Sand rock (little water)	10	903
Sand rock (small flow)	10	500	Rotten lime rock	25	928
Light shale	300	800	Very hard rock (stopped)	2	930
Iron pyrites and lime cap rock	8	808			

This bore evidently penetrates a close grained hard rock, which does not admit of water passing freely through it. The size of the casing, being 6 inches, with maximum pressure of 137 pounds per square inch, would indicate the flow would be much greater than it is. It is quite probable another flow below can be found in the more open rock. This theory is supported by the log of the Risdon well, only 12 miles in an easterly direction. After the well has been discharging freely for some time it takes about eighteen hours for it to reach its maximum pressure after the water is shut off. It is cased with 800 feet of 6-inch steel casing, weighing 18 pounds per foot. At the bottom is 96 feet of 5-inch casing, which laps on the outside casing 20 feet, and the lower 24 feet is perforated with three-fourths inch holes.

Scotland well.—Located in sec. 8, T. 96 N., R. 58 W., town of Scotland, county of Bon Homme, State of South Dakota. Owned by town of Scotland. Completed in 1887. Drilled by Carr and Ritchie, Yankton, S. Dak. Depth, 587 feet. Cost $2,050, or $3.49 per foot. Flow, 9 gallons per minute. Elevation above sea level, 1,338 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Black loam	4	4	Blue shale	40	399
Yellow clay	40	44	Quicksand	30	429
Blue clay	15	59	Blue shale	35	464
White chalk	60	119	Quicksand	30	494
Blue chalk	60	179	Lime rock	13	507
Blue shale	80	259	Water bearing sand rock	28	535
Grey sand rock	100	359	Quartzite	52	587

Stopped in quartzite.

This well is now abandoned. A small flow was struck at 512 feet from the surface at an elevation of 826 feet above sea level, indicating that it is one of the uppermost veins in the basin. The bore stopped in quartzite, which indicates that it is on the eastern edge of the artesian basin.

Springfield well.—Located in T. 92 N., R. 60 W., town of Springfield, county of Bon Homme, State of South Dakota. Owned by Bonesteel and Turner. Commenced winter of 1891. Completed spring of 1891. Drilled by Grey Bros., Milwaukee, Wis. Depth, 592 feet. Cost, $2,400, or $3.50 per foot. Flow, 3,290 gallons per minute. Pressure, 85 pounds per square inch when flow is shut off. Temperature of water, 65 degrees. Elevation above sea level, 1,275 feet.

Strata passed through are as follows:

	Thickness.	Totals.		Thickness.	Totals.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil and clay	50	50	Shale and sand (flow of soft water)	75	516
Chalk rock	100	150	Hard cap rock	12	528
Shale	290	440	Water-bearing sand rock	62	592

This well discharges the largest amount of water in the Dakota basin, although the closed pressure of the well is only about half that of some of the others. This is an indication of a very open and porous water-bearing rock. The discharge from this well is nearly what it would be if the lower end of the casing entered a subterranean lake of water; therefore there is but little resistance to the water moving through the rock strata. The water is used to drive a 100-barrel flour mill, which is done by the power developed by a common turbine water wheel. The well is cased with 590 feet of 8-inch casing.

Tyndall well.—Located in Sec. 6, T. 94, R. 59, town of Tyndall, county of Bon Homme, State of South Dakota. Owned by town of Tyndall. Completed in 1888. Drilled by Carr & Ritchie, Yankton, S. Dak. Depth, 735 feet. Cost, $2,544, or $3.46 per foot. Flow, 530 gallons per minute. Pressure, 35 pounds per square inch when flow is shut off. Temperature of water is 62 degrees. Elevation above sea level, 1,410 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Loam	4	4	Shale	75	397
Yellow clay	40	44	Sand	60	457
Blue clay	171	215	Shale	242	699
Shale	100	315	Water bearing sand rock	35	734
Hard rock	7	322	Stopped on quartz.		

This bore is reported to have reached quartzite at about 735 feet from the surface, or 675 feet above sea level, which is 128 feet above the quartzite in the Scotland bore, some 14 miles to the northeast. The flow has decreased about 20 gallons per minute during the last year. The water is hard and is used for town purposes. The well is cased with 4½-inch casing.

Layson well.—Located in Sec. 22, T. 94 N., R. 61 W., 8 miles southwest of Tyndall, county of Bon Homme, State of South Dakota. Owned by H. P. Layson. Commenced

October, 1890. Completed April, 1891. Drilled by H. P. Layson. Depth, 1,075 feet. Flow very weak, 1 gallon in three minutes; just comes to surface.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	3	3	Soapstone	300	765
Yellow clay	32	35	Iron pyrites and tough clay	45	810
Blue clay	55	90	Sandstone (very little water)	230	1,040
Chalk rock	280	370	Coarse sand and gravel	3	1,043
Very hard limestone	20	390	Hard stone	3	1,046
Black clay	14	404	Black mud	27	1,074
Very hard stone	1	405	Hard rock (made 1 foot 8 inches in three or four days and quit)	2	1,075
Light colored clay (gray shale)	60	465			

This bore stops in very hard rock, probably quartzite, in which only 20 inches could be drilled in three days. A stratum of sand rock 230 feet thick was struck at 810 feet from the surface, in which a small amount of water was found, which just rises to the surface. This bore is cased with 400 feet of 3-inch casing, 435 of 2½ inch, which laps 79 feet on the 3-inch casing. The lower casing is seated in grey shale 319 feet above the bottom of the bore. The flow not being sufficient to supply the amount of water required, a windmill is used to pump the water into a tank for domestic use and stock purposes. When allowed to flow the water is clear, but when pumped by the windmill it is muddy. About 1 foot of blue tar-like mud settles on the bottom of the tank each month. Cost of drilling this bore and 400 feet of another one, which was abandoned, was as follows: Freight on pipe, $50.48; casing, $433.20; cost of tools and labor, $805.50; hauling water and boarding men, $596.18; total, $1,885.36. Horse power was used to drive the drilling machinery. The pressure is only sufficient to raise the water 7 feet above the surface.

Mill well.—Located in sec. 6, T. 94 N., R. 59 W., town of Tyndall, county of Bon Homme, State of South Dakota. Commenced March 20, 1891. Completed September 3, 1891. Depth, 752 feet. Flow large, fills an 8-inch pipe. Pressure, 40 pounds per square inch when flow is shut off. Elevation above sea level, 1,410 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Loam	4	4	Shale	75	397
Yellow clay	40	44	Sand rock	60	457
Blue clay	171	215	Shale	243	700
Shale	100	315	Water bearing sand rock	52	752
Hard rock	7	322			

Milwaukee Railroad well.—Located in T. 123 N., 64 W., town of Aberdeen, county of Brown, State of South Dakota. Owned by Chicago, Milwaukee and St. Paul Railroad. Completed March, 1882. Drilled by Swan Brothers. Depth, 955 feet. Cost, $4,300, or $4.50 per foot. Pressure, 100 pounds per square inch when flow is shut off. Elevation above sea level, 1,300 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil, clay and sand	36	36	Sandstone	15	910
Blue clay	64	100	Lime, shale and sandstone	30	940
Blue shale	410	510	Sandstone (main flow)	15	955
Limestone	20	530	Stopped on hard bottom.		
Blue shale streaks limestone (small flow)	365	895			

This is the first bore put down which reached the artesian basin of the Dakotas. It was made by the Chicago, Milwaukee and St. Paul Railroad Company in 1881-'82 for the purpose of obtaining water for engine use, but could not be used for that purpose on account of its quality, it being hard and foams badly in the boilers.

When first struck it threw up large quantities of rock when left to flow freely. In 1886 it became choked up (probably by caving below casing). After it was cleaned out a 3-inch casing was put down 910 feet. Since this was done the water has been clear. The water is used for reinforcing the domestic supply of the city of Aberdeen. It is said that live fish have come up with the water. The man having charge of the water service of the railroad reports that large numbers of small fish have been found in the water tank, which is supplied by a pipe directly connected with the well. The well is cased with 3-inch, 4½-inch, 6-inch, and 8-inch casing, the 8-inch extending to 510 feet; the 3-inch extends from the top to 910 feet from the surface.

City well No. 1.—Located in T. 123 N., R. 64 W., town of Aberdeen, county of Brown, State of South Dakota. Owned by town of Aberdeen. Completed in 1882. Drilled by Gray Brothers, Milwaukee, Wis. Depth, 918 feet. Cost, $4,000, or $4.35 per foot. Flow, 330 gallons per minute. Pressure, 40 pounds per square inch when flow is shut off. Temperature of water, 66 degrees. Elevation above sea level, 1,300 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil and clay	16	16	Sand (some water)	10	889
Blue clay	78	94	Shale	15	904
Shale	400	494	Iron pyrites (cap rock)	1	905
Iron pyrites and shale	10	504	Sand rock, water	13	918
Blue shale	375	879			

This well is the first, if not the very first, put down in the Dakotas to obtain water for municipal purposes. At first both the flow and pressure were stronger than they are at the present time, but the action of the well, which at first resembled the railroad well, is only a few hundred feet distant. The two wells do not seem to have any connection with each other; that is, the flow of one does not seem to interfere with that of the other. It is quite probable that this well has caved in, and as a consequence its flow is greatly diminished. The well is cased with 905 feet of 3$\frac{3}{16}$-inch casing.

City well No. 2.—Located in T. 123 N., R. 64 W., town of Aberdeen, county of Brown, State of South Dakota. Owned by city of Aberdeen. Drilled by Gray Bros., Milwaukee, Wis. Depth, 1,004 feet. Cost, $4,000, or $4 per foot. Flow, 825 gallons per minute. Pressure, 62 pounds per square inch when flow is shut off. Temperature of water, 66 degrees. Elevation above sea level, 1,300 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil and clay	110	110	Shale	344	940
Shale	450	560	Hard sand-rock cap	6	946
Shale, sand, and iron pyrites	35	595	Sand rock (flow)	45	991
Sandstone, water (not flow)	1	596	Shale	13	1,004
			Stopped in shale.		

This well was put down for power purposes by the city of Aberdeen. The water under pressure from the well is applied to a double action duplex piston pump, which is used to pump the sewage from the well into a conduit laid just below the surface. The power is ample and very steady, requiring no attention except to occasionally oil the machinery. The lift is about 20 feet and the capacity sufficient to raise 2,500,000 gallons per day. Both the flow and pressure have decreased a little since the well was put down. It is reported to have flowed 1,000 gallons per minute. Its flow now is 825. The well is cased down to 700 feet with a 6-inch casing, then with 270 feet of 5 inch, which laps 30 feet on the 6-inch casing; then 71 feet of 4-inch, which laps 20 feet on the 5-inch, the lower 12 feet being perforated.

City well No. 3.—Town of Aberdeen, country Bown, State of South Dakota. Owned by city of Aberdeen. Drilled by American Well Works (Wheeler). Depth, 1,066 feet. Elevation above sea level, 1,300 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
This log begins at		835	Sandstone (flow)	20	941
Iron pyrites, lime, etc	2	837	Hard shale (almost slate)	25	966
Black mud and loose rock	53	890	Hard, fine sandstone (no water)	18	984
Sandstone, water	22	912	Sandy shale	32	1,016
Sandstone and lignite	5	917	Loose sandstone (main flow)	50	1,066
Hard sandstone, cap rock	4	921	Bottom on hard material.		

This bore was made by the city of Aberdeen with the hope of obtaining a supply of clear water for municipal purposes. It is cased with 8-inch casing to the top of the cap rock (917 feet.) From this point a 2-inch bore is made to the depth of 1,066 feet. This was a prospecting bore through the water-bearing strata for the purpose of discovering the clear-water veins. One or two small flows were found just below the cap rock. The main flow was struck at about 1,020 feet, which is a strong flow for a 2-inch bore.

Large quantities of coarse sand were thrown up with the water. In attempting to enlarge the bore the drilling tools became fastened in the sand, and after spending a few weeks in an unsuccessful effort to remove them work has been suspended for the present.

Beard well.—Located in Sec. 20, T. 123 N., R. 63 W., town of Aberdeen, county of Brown, State of South Dakota. Owned by H. C. Beard. Commenced July, 1890. Completed October, 1890. Drilled by Gray Bros., Milwaukee, Wis. Depth, 1,050 feet. Cost, $3,050, or $3 per foot. Flow, 1,060 gallons per minute. Pressure 138 pounds per square inch when flow is shut off. Elevation above sea level, 1,303 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil and clay	140	140	Shale	37	997
Clay and bowlders	60	200	Hard sand rock (cap)	3	1,000
Shale	740	940	Loose sand rock (flow)	50	1,050
Sand rock and iron pyrites	20	960			

This well was put down for irrigation purposes. The flow of the well during the winter of 1890–'91 was used for wetting the land during cold weather. The land was covered with a thick sheet of ice, and the land so covered required no irrigation the following summer. Connected with this well is a 3-acre reservoir, which has a holding capacity of 15 acre feet. By the aid of the reservoir, about 300 acres have been irrigated the present season. The well is cased with 6-inch casing to 970 feet, then with 50 feet of 5-inch casing, which laps 23 feet on the 6-inch.

Columbia well.—Located in Sec. 29, T. 125 N., R. 62 W., town of Columbia, county of Brown, State of South Dakota. Owned by town of Columbia. Completed in 1886. Drilled by Swan Bros., Andover, S. Dak. Depth, 964 feet. Cost, $3,200, or $3.32 per foot. Flow, 940 gallons per minute (1,400 in 1890). Pressure, 160 pounds per square inch when flow is shut off. Temperature of water, 63 degrees. Elevation above sea level, 1,315 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Yellow clay	20	20	Blue shale	200	719
Quicksand	8	28	Sandstone	2	721
Blue clay	10	38	Sandy shale (small flow)	30	751
Quicksand	30	68	Gray shale	50	801
Gravel	14	82	Sandy shale (small flow)	55	856
Blue clay	8	90	Broken limestone	6	862
Quicksand	15	105	Sandstone (flow)	5	867
Hardpan	9	114	Blue shale	20	887
Gray shale	355	469	Iron pyrites and lime	5	892
Hard limestone	2	471	Sandstone (flow)	10	902
Tough blue shale	43	514	Lime, sand, and shale	25	927
Hard limestone	5	519	Sandstone (main flow)	37	964

This well was put down for domestic and fire purposes. Water, soft but discolored, and when allowed to stand a fine sediment is deposited, resembling blue mud. It is claimed that the water from this well, as that of many other artesian wells, has some peculiar property which extinguishes fire more rapidly than that of ordinary water. Experienced firemen confirm this report. The closed pressure of the water in the well is the same as last year, but the flow is not as large. The apparent decrease may be due to different results obtained by the two methods of measurement. The well is cased with 900 feet of 4½-inch casing.

Flanders well.—Located in sec. 31, T. 126 N., R. 61 W., county of Brown, State of South Dakota. Owned by Charles Flanders. Drilled by Charles Flanders. Depth, 965 feet. Cost, $3,000, or $3.11 per foot. Pressure, 135 pounds per square inch when flow is shut off.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	2	2	Gray shale	40	724
Clay	20	22	Sandy shale (second small flow)	50	774
Quicksand	30	52	Broken limestone	8	782
Cemented gravel	10	62	Sandstone (third small flow)	3	785
Blue clay	10	72	Blue shale	20	805
Shale (bowlders in upper part)	300	*372	Iron pyrites and lime	5	810
Soapstone	100	472	Gray shale	20	830
Limestone	6	478	Limestone	50	880
Blue shale	150	628	Limestone and shale	32	912
Hard rock	3	631	Sandstone (main flow)	10	922
Gray shale	50	681	Limestone and shale	28	950
Sandy shale (first small flow)	3	684	Shale	15	965

This well was put down for irrigation purposes. Quantities of sand came up with the water, and in June last it became so choked up with sand as to stop its flow.

Heman well.—Located in Sec. 3, T. 125 N., R. 61 W., county of Brown, State of South Dakota. Owned by H. L. Heman. Commenced January 13, 1891. Drilled by H. L. Heman. Cost, $2,860. Elevation above sea level, 1,350 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil and clay	96	96	Clay and shale layers	119	640
Sand and gravel	14	110	Iron pyrites and lime	2	642
Shale	202	312	Shale and clay marl	20	662
Lime rock	7	320	Iron pyrites and lime	7	667
Soapstone (some shale)	100	420	Soft clay marl (some black sand)		
Clay	50	470	Quicksand	30	697
Soapstone	42	512	Soapstone	19	716
Lime rock	9	521			

This well was put down for irrigation purposes. Mr. Heman purchased a drilling rig and put a well down by common labor, and gives the following items of the cost: Drilling and tools, $1,800; derrick, $300; hauling water, $200; fuel, $300; casing, 716 feet of 6-inch, $600; boarding men, $150; lumber, $150; railroad freight on casing and machinery, $160; hauling material 10 miles, $90; total, $2,850.

Frederick well.—Located in Sec. 11, T. 127 N., R. 64 W., town of Frederick, county of Brown, State of South Dakota. Owned by town of Frederick. Commenced August 14, 1889. Completed May 15, 1890. Drilled by Swanson, Minneapolis, Minn. Depth, 1,139 feet. Cost, $3,600, or $3.16 per foot. Flow, 135 gallons per minute. Pressure, 70 pounds per square inch when flow is shut off. Temperature of water, 69 degrees. Elevation above sea level, 1,383 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil and clay	120	120	Shale	62	1,048
Shale	775	895	Lime rock	7	1,055
Lime and shale	75	970	Alternating hard and soft sand rock (some shale three or four flows)	84	1,139
Iron pyrites and lime	15	985			
Sand (water 3 or 4 gals. min)	1	986			

This well was put down by the town for water for domestic use, but on account of its muddy character it is not generally used for that purpose. Arrangements are being made to use the water for irrigation. In the lower 90 feet the bore penetrates alternating layers of soft sand rock and shales, in which three or four flows of water were found. It is probable the disintegration of the soft rock which is brought up with the flow causes the muddy appearance and the fine sand soon settles, but the clay remains suspended in the water for several days. When the well is allowed to flow freely fragments of iron pyrites, shale, and gravel are brought up with the water. This is one of that kind of wells that increases in pressure for several hours or even days after the flow is shut off, and when opened the flow decreases in the same way until the normal flow is reached, which corresponds somewhat to the time required to gain its maximum pressure, though generally the pressure responds more quickly than the flow. The well is cased with 650 feet of 6-inch casing and 1,038 feet of 4½. The latter comes to the surface.*

Krouschnabel well.—Located in Sec. 12, T. 127 N., R. 63 W., town 7 miles east of Frederick, county of Brown, State of South Dakota. Owned by Caspar Krouschnabel. Drilled by Caspar Krouschnabel. Commenced September 25, 1890. Elevation above sea level, 1,375 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	2	2	Soapstone (hard and soft layers)	555	740
Yellow clay and boulders	63	65	Soft blue clay (some black grit)	60	800
Blue clay (no boulders)	60	125	Iron pyrites	1	801
Slate	60	185	Rotten limestone and shale	65	866

Work on this well was stopped in June and started again on the 10th of December. At 865 feet a small flow was struck. Work on the bore is still in progress.

Abbott well.—Located in Sec. 21, T. 127 N., R. 63 W., town 5 miles southeast of Frederick, county of Brown, State of South Dakota. Owned by Abbott & Morgan. Commenced December 27, 1890. Drilled by Abbott & Morgan. Elevation above sea level, 1,405 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	2	2	Slate	91	428
Yellow clay	20	22	Hard soapstone (some slate)	19	447
Gravel and loose rock	10	32	Hard slate and lime	30	477
Clay, gravel and sand	13	45	Sandy material (some clay)	52	529
Sand (surface water)	140	185	Hard slate and sand	69	598
Clay and sand	106	291	Hard slate (little lime)	81	679
Sand (hard)	22	313	Shales (little lime)	150	829
Hard sand and clay	24	337			

Groton well No. 2.—Located in Sec. 19, T. 123 N., R. 60 W., town of Groton, county of Brown, State of South Dakota. Owned by town of Groton. Commenced June, 1889. Completed August, 1889. Drilled by Swan Bros., Andover, S. Dak. Depth, 922 feet. Flow, 830 gallons per minute in 1890. Pressure, 135 pounds, in 1890, per square inch when flow is shut off. Elevation above sea level, 1,304 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	2	2	Gray shale	120	445
Yellow clay	25	27	Limestone	4	449
Blue clay	35	62	Blue shale	430	879
Blue shale	260	322	Limestone	10	889
Limestone	3	325	Sandstone (flow)	33	922

---

* This log is not reliable.

This well was put down for domestic purposes. Water, quite muddy. When flowing freely quantities of shale are brought up with the water. The well became choked up in May last and failed to flow for two weeks. Cased with 658 feet of 6-inch and 853 feet of 4½. Casing on latter comes to the top. Inside of this is 157 feet of 3-inch pipe, which is perforated at the bottom.

F. D. Adams well.—Located in Sec. 8, T. 123 N., R. 60 W., town of Groton, county of Brown, State of South Dakota. Owned by F. D. Adams. Commenced February 12, 1891. Completed May 4, 1891. Drilled by John Anderson. Depth, 977 feet. Cost, $1,500, or $1.53 per foot. Flow, 105 gallons per minute; August 10, 255 gallons. Pressure, 80 pounds per square inch when flow is shut off. Temperature of water, 62 degrees. Elevation above sea level 1,305 feet.

Strata passed through are as follows:

	Thickness.	Total.
	Feet.	*Feet.*
Soil and blue clay	102	102
Cemented gravel	6	108
Blue shale	25	133
Iron pyrites and lime	2	135
Grey shale	100	235
Iron pyrites and lime	2	237
Hard blue shale	10	247
Iron pyrites and lime	3	250
Grey shale	100	350
Limestone	1	351
Grey shale and limestone streaks	100	451
Grey shale	100	551
Hard sandstone	2	553
Grey shale	100	653
Granite	3	656
Soapstone	75	731
Granite very hard	1	732
Grey shale	100	832
Fine white sand	20	852
Hard rock	2	854
Hard blue shale	50	904
Hard rock	2	906
Sand rock (first flow)	10	916
Hard cap rock	1	917
Sand rock (flow)	60	977

This well was put down for irrigation purposes, but the water has not yet been utilized for this purpose. In the bottom of the bore are two drills and about 200 feet of drill rods, which probably greatly impede the flow.

Burnham well.—Located in Sec. 31, T. 124 N., R. 60 W., town of Groton, county of Brown, State of South Dakota. Owned by W. A. Burnham. Commenced November 7, 1890. Completed January 27, 1891. Drilled by W. A. Burnham. Depth, 942 feet. Cost, $2,500, or $2.65 per foot. Flow, 150 gallons per minute. Pressure, 137 pounds per square inch when flow is shut off. Temperature of water, 63 degrees. Elevation above sea level, 1,306 feet.

Strata passed through are as follows:

	Thickness.	Total.
	Feet.	*Feet.*
Soil	2	2
Yellow clay	22	24
Quicksand	20	44
Blue shale	40	84
Cobblestones	4	88
Cemented gravel	20	108
Blue shale	100	208
Hard sand rock	2	210
Blue shale	150	360
Brown lime	3	363
Blue shale	25	388
Iron pyrites	3	391
Blue shale	70	461
Boulders	18	479
Grey shale	246	725
Sand rock (first flow)	41	766
Blue shale	40	806
Quicksand	10	816
Iron pyrites (cap rock)	4	820
Shale	20	840
Sand and slate (water)	102	942

This well was put down mainly for irrigation purposes, but very little has yet been done. When first completed if allowed to flow freely quantities of shale and gravel were carried up with the water. On April 10 it became choked up and was partially opened June 25. Cased with 4-inch casing to 816 feet, and inside of this is 150 feet of 2½-inch pipe, which is perforated with ½-inch holes.

Groton Well No. 1.—Located in Sec. 19, T. 123 N., R. 60 W., town of Groton, county of Brown, State of South Dakota. Owned by town of Groton. Drilled by Gray Bros., Milwaukee, Wis. Depth, 900 feet. Elevation above sea level, 1,304 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	2	2	Limestone	4	469
Yellow clay	25	27	Blue shale	451	920
Blue clay	35	62	Limestone, sandy, cap rock	5	925
Blue shale	270	332	Sandstone (flow)	35	960
Limestone	3	335			
Gray shale	130	465			

This well was put down for municipal purposes. Soon after it was completed the seating of the casing gave way and the flow came up on the outside of the casing, which washed out a hole at the surface 30 feet in diameter and 100 feet deep. It will be observed the seating of the outside casing was in blue shale. The bore was cased with 840 feet of 5$\frac{3}{16}$-inch casing; 140 feet of 4½ inch, which laps 60 feet on the 5$\frac{3}{16}$ inch; then 75 of 3¼-inch casing, which laps 35 feet on the 4½. The lower part of the 3¼-inch pipe is perforated with ¼-inch holes.

Kimball well.—Located in Sec. 3, T. 103 N., R. 68 W., town of Kimball, county of Brule, State of South Dakota. Owned by town of Kimball. Completed in 1887. Drilled by Gray Bros., Milwaukee, Wis. Depth, 1068 feet. Cost, $4,500, or $4.21 per foot. Flow, 186 gallons per minute. Pressure, 20 pounds per square inch when flow is shut off. Temperature of water, 68 degrees. Elevation above sea level, 1781, feet.

Strata passed through are as follows:

	Thickness.	Totals.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Clay	230	230	Salt and rock	20	980
Quicksand	100	330	Hard rock	8	988
Shale	610	940	Soft sand rock	80	1,068
Sand rock	20	960	Stopped in soft sand rock.		

This well is used as a public watering place. The water is hard, but clear. The well is on the high country between the Missouri and James rivers. The well is cased with a single string of 988 feet of 4½ inch casing. The well is said to be decreasing in its flow. It requires one-half hour to reach its maximum pressure after the flow has been shut off.

City well.—Located in Sec. 15, T. 104 N., R. 71 W., town of Chamberlain, county of Brule, State of South Dakota. Owned by city. Commenced October, 1890; completed May, 1891. Drilled by Page Guthrie. Depth, 785 feet. Cost, $3,500, or $3.46 per foot. Flow, 529 gallons per minute. Pressure, 122 pounds per square inch when flow is shut off. Temperature of water, 74 degrees. Elevation above sea level, 1,547 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	3	3	Shale	12	550
Clay	17	20	Shale with layers of soft sand	50	600
Clay	10	30	Shale	20	620
Clay	80	110	Shale	30	650
Blue clay	15	125	Shale	25	675
Shale	10	135	Shale	25	700
Chalk rock	65	200	Shale	13	713
Dark chalk rock	50	250	Iron pyrites and sand rock (first flow)	2	715
Chalk rock	50	300	Sand rock	4	719
Chalk rock	100	400	Shale	33	752
Chalk rock	15	415	Shale	6	758
Shale	35	450	Sand rock (second flow)	2	760
Shale	50	500	Sand rock	15	775
Slate	21	521	Shale	5	780
Sand rock	4	525	Iron pyrites, sand, and shale	5	785
Sand rock	13	538			

This well was put down by the city of Chamberlain for municipal purposes. It is located on a hill considerably above the city, where there is a settling reservoir sufficiently elevated above the city to afford good pressure for fire purposes. Mr. Scott Hayes, city engineer, who superintended the work of making this bore, has furnished us with the record of the well. It is so complete that I give most of it as a good example to follow for those putting down artesian wells. In addition to the log of the strata and other data given, he furnished the department with samples of all the strata penetrated, which will in due time be arranged in a glass tube, about 8 feet long, showing the order and thickness of the strata as they lie in that locality. The first flow was struck at 716 feet, one gallon per minute from the top of the pipe. Quality bad, quite salty. The second flow was struck at 750 feet. This flow was one-half gallon per minute, but better quaity than the first. The third flow was struck at 780 feet; flow 7½ gallons per minute. The temperature of all the flows at this point was 64°. Pressure at the top of the well, 55 pounds per square inch. Quality good. The fourth flow was struck at 785 feet. The total flow at this point is 539 gallons per minute. Temperature, 74°. Pressure, 122 pounds per square inch. Quality good. Tests with litmus papers, result neutral. Specific gravity, 1,000. When the well is closed the pressure gradually runs up to 100 pounds and increases to 122 pounds in 24 hours. The flow supports a 2-inch stream 45 feet high, and a 4-inch stream 6¼ feet high, and a 6-inch stream 10 inches above the top of the pipe. Within four months after the well was completed the flow was observed to be somewhat diminished. This has occurred twice. Each time there was considerable mud came up with the water, but as soon as the water became clear the flow increased. The amount of mud thrown out alltogether is estimated to be 100 cubic yards. The well is cased to 770 feet with 6-inch casing. There is about 300 feet of 8-inch casing near the top of the well, which was intended to be pulled out, but it was found impossible to do so with the appliances at hand. The well was put down by contract in city bonds.*

Hammer well.—Located in sec. 19, T. 99 N., R. 69 W., town of Castalia, county of Charles Mix, State of South Dakota. Owned by A. A. Hammer. Completed May, 1891. Depth, 966 feet. Cost, about $1,500, or $1.55 per foot. Flow, 30 gallons per minute. Pressure, 50 pounds per square inch when flow is shut off. Elevation above sea level, 1,610 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil and clay	87	87	Dark sticky shale	45	675
Chalk rock	212	299	Blue shale	60	735
Hard rock	30	329	Iron pyrites and hard rock	20	755
Chalk rock	160	489	Soft rock with iron pyrites	100	855
Water-bearing sandstone	1	490	Water-bearing sandstone	111	966
Chalk rock	140	630	Hard and soft streaks		

This is a small bore put down for water for household use and for irrigating one-half acre of garden. Quality of water hard, but clear. Cased with 755 feet of 2-inch pipe, then with 1¼-inch pipe to the bottom.

Mitchell well.—Located in Sec. 22, T. 103 N., R. 60 W., town of Mitchell, county of Davison, State of South Dakota. Owned by city of Mitchell. Completed January 9, 1886. Drilled by Mars & Miller, Chicago, Ill. Depth, 548 feet. Cost, $3,130, or $5.75 per foot. Pressure, 7 pounds per square inch when flow is shut off. Elevation above sea level, 1,316 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Loam	3	3	Sand rock (water)	29	315
Sandy loam	37	40	Blue shale	134	449
Blue clay	90	130	Dry sand	30	479
White sand	40	170	Blue shale	53	532
Blue shale	115	285	Hard cap rock	1	533
Iron pyrites and lime	1	286	Sand rock (water)	15	548

This well was put down for domestic and fire purposes, but failing to get sufficient pressure the water from the well is forced into distributing mains of the city of Mitchell by steam pumps. By this means the city is supplied with water.

---

*Elevations given are from the United States Missouri River Commission Surveys.

Unnamed well.—Located in Sec. 35, T. 104 N., R. 60 W., town 4 miles northeast of Mitchell, county of Davison, State of South Dakota. Owned by American Investment Company. Completed April, 1891. Drilled by Thos. Ball, Mitchell, S. Dak. Depth, 507 feet. Flow, 40 gallons per minute. Temperature of water, 56 degrees. Elevation above sea level, 1,344 feet.

This well was put down for irrigation purposes, but is not used. It is cased with 4½-inch casing to 255 feet, then with 270 feet of 3-inch, which laps on the bottom of the 4½-inch. Well flows a small amount of hard, but clear water.

Schlund well.—Located in sec. 3, T. 103 N., R. 60 W., town 4 miles north of Mount Vernon, county of Davison, State of South Dakota. Owned by W. H. Schlund. Completed October, 1890. Drilled by Schlund. Depth, 338 feet. Flow, 40 gallons per minute. Elevation above sea level, 1,375 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Earth	36	36	Iron pyrites and lime	3½	246½
Sand rock	4	40	Shale	24	270½
Shale	96	136	Shale and hard streaked to bottom	67	338
Sand rock	7	143	Sand rock in bottom.		
Shale	100	243			

This well was put down for irrigation purposes, but there is but little data concerning it. It is cased with 138 feet of 4 inch casing, which is seated in sand rock. Inside of this is 3-inch casing, length unknown. Elevations given are approximate.

Andover well.—Located in sec. 35, T. 123 N., R. 59 W., town of Andover, county of Day, State of South Dakota. Owned by Chicago, Milwaukee, and St. Paul Railroad. Completed in 1882. Drilled by Swan Brothers, Andover, South Dakota. Depth, 1,075 feet. Pressure, 65 pounds per square inch when flow is shut off. Elevation above sea level, 1,505 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil, sand, and clay	45	45	Limestone	15	590
Blue clay	30	75	Shale streaks limestone	480	1,070
Blue shale	500	575	Sandstone (main flow)	5	1,075

This well was put down for railroad purposes, but the water was found to be unsuitable for boiler use. It now serves the town of Andover for domestic purposes. The water is soft and clear but contains minerals which causes it to foam badly in steam boilers. It is cased to 725 feet with a 6-inch casing, which is seated in shale. Inside of this is 1,050 feet of 4½-inch casing, which extends from the top to the bottom of the bore. The piping from this well is so arranged that its flow can not be measured, but it is sufficient to serve the town.

Armour well.—Located in sec. 11, T. 98 N., R. 64 W., town of Armour, county of Douglas, State of South Dakota. Owned by town of Armour. Commenced November 25, 1890. Completed January 7, 1891. Drilled by Swan Brothers. Depth, 757½ feet. Cost $3,030, or $4 per foot. Flow, 1,500 gallons per minute. Pressure, 55 pounds per square inch when flow is shut off. Temperature of water 60 degrees. Elevation above sea level, 1,514 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	1		Gray sand rock (very soft)	22	388
Yellow clay (sandy)	39	40	Blue shale	52	440
Blue clay (greasy)	47	87	Soapstone	25	465
Blue shale	119	206	Gray shale	88	553
Black shale	49	255	Blue shale	53	606
Chalk rock	52	307	Lime rock (yellowish)	15	621
Lime rock (blue)	26	333	Blue shale	70	691
Yellow sand rock	23	356	Layers of sand and shale	10	701
Yellowish sand rock (soft)	10	366	Sand rock (pure)	56	757

The water of this well is used for town purposes. It is stated the pressure and volume are sufficient to support a 2-inch stream 50 feet high; a 4½-inch stream 17 feet high; and a 6 inch stream 6½ feet high. If these figures are correct it shows there is little or no resistance to the water passing through the rock as it approaches the lower end of the casing. The well is cased with 206 feet of 8-inch casing which is seated in black shale. Inside of this is a string of 708 feet of 6-inch casing which comes to the top of the bore. There is a good strong flow of hard, clear water.

Ipswich well.—Located in sec. 27, T. 123 N., R. 68 W., town of Ipswich, county of Edmunds, State of South Dakota. Owned by town of Ipswich. Completed fall, 1884. Drilled by Grey Brothers, Milwaukee, Wis. Depth, 1,230 feet. Cost, $5,298, or $4.30 per foot. Flow, 40 gallons per minute. Pressure, 106 pounds per square inch when flow is shut off. Temperature of water, 71 degrees. Elevation above sea level, 1,531 feet. No record of strata given.

This well was put down for domestic and fire protection purposes. The water is strongly impregnated with mineral of some kind, which has destroyed the casing at the bottom. The well is said to be cased with 1,000 feet of 4½-inch casing, and inside of this is 330 feet of 3½-inch, which laps 100 feet on the outside casing. It is thought that this casing has been destroyed by the bad water, and has fallen down to the bottom of the bore and shut off the lower flow. While the pressure remains the same the flow has decreased. It is reported that at one time fish came up with the water in large numbers, but none have been seen during the last year or so.

Orient well.—Located in sec. 18, T. 117 N., R. 68 W., town near Orient, county of Faulk, State of South Dakota. Owned by Faulk County. Completed June, 1891. Drilled by Swan Brothers, Andover, S. Dak. Depth, 1,215 feet. Cost, $4,800, or $4 per foot. Flow, 950 gallons per minute. Pressure, 130 pounds per square inch when flow is shut off. Temperature of water, 75 degrees. Elevation above sea level, 1,565 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Yellow clay	30	30	Blue shale (with hard streaks)	43	477
Blue clay	17	47	Gray shale (gaseous)	198	675
Black slate	30	77	Blue shale (cavey)	260	935
Blue shale	216	293	Blue shale (streaks iron pyrites)	145	1,080
Gray shale	38	331	Hard sand rock (flow water)	40	1,120
Blue shale caving (hard streaks)	60	391	Streaks sand, lime, iron pyrites, and shale	45	1,165
Lime rock (small vein water under it)	3	394	Sand rock (hard and soft layers, flow)	50	1,215
Black shale	40	434			

This well was put down by Faulk County as a test well for irrigation purposes. The parties owning the land in the vicinity have an option on it, or agreed to pay the cost price for it, provided it proved to be a success. The bore is cased with 1,070 feet of 6-inch casing and 95 feet of 5½-inch, with no lap. The 5½-inch casing is perforated. When drilling was stopped the flow was 150 gallons per minute. Pressure, 130 pounds. Two days afterwards large quantities of sand began to come up with the water and the flow increased to 950 gallons per minute. When the sand stopped running the water continued to be discolored, probably by the eroding of the shales.

Miller well.—Located in sec. 10, T. 112 N., R. 68 W., town of Miller, county of Hand, State of South Dakota. Owned by town of Miller. Completed in 1886. Drilled by Gray Brothers, Milwaukee, Wis. Depth, 1,145 feet. Cost, $4,010, or $3.50 per foot. Flow, 400 gallons per minute. Pressure, 100 pounds per square inch when flow is shut off. Temperature, 78 degrees. Elevation above sea level, 1,586 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil, clay, and gravel	120	120	Shale	230	1,105
Blue shale	710	830	Hard sand rock (cap rock)	6	1,111
Hard sand rock and iron pyrites	45	875	Sand rock (flow)	5	1,116
			Sand rock (no flow)	29	1,145

This well was put down for town use. The water is reported to destroy iron vessels and pipes quickly. The well is cased as follows: 510 feet of 6¼-inch casing, which is seated in blue shale, then 460 feet of 5½-inch casing, which laps 40 feet on the 6¼-inch, and is seated on the top of a hard sand rock; then there is 207 feet of 4½-inch casing, which laps 38 feet on the 5½-inch. This is also seated on the next lower sand rock, which is called the cap rock and overlies the water bearing sand rock. Inside the 4½-inch casing is 60 feet of 3¼-inch casing, which rests on the bottom of the bore and laps 20 feet on the 4½-inch, which is perforated below the lap with ten ½-inch holes to the foot. This bore is so cased as to admit the lower flow, which has a high temperature of 78 degrees.

Harold well.—Located in sec. 8, T. 112 N., R. 74 W., town of Harold, county of Hughes, State of South Dakota. Owned by town of Harold. Completed in 1888. Drilled by Swan Brothers, Andover, S. Dak. Depth, 1,453 feet. Flow, 35 gallons per minute. Pressure, 27 pounds per square inch when flow is shut off. Temperature of water, 94 degrees. Elevation above sea level, 1,800 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	2	2	Black shale	50	600
Yellow clay	38	40	Black sandy shale	140	740
Blue clay	70	110	Gray shale	160	900
Bowlders in clay	15	125	Blue shale	400	1,300
Blue shale	155	280	Blue shale (streaks of lime)	133	1,433
Limestone	2	282	Lignite	2	1,435
Blue shale	168	450	Sandstone (main flow)	16	1,451
Gray shale (streaks limestone)	100	550	Brown shale	2	1,453

The water from this well is used for town purposes. Its flow is reported as decreasing slowly. It is cased with a 4-inch casing all the way. The temperature of the water is the highest of any yet observed. A small flow was found at 1,000 feet, and three were found between 1,300 and 1,433 feet.

Highmore well.—Located in Sec. 12, T. 112 N., R. 73 W., town of Highmore, county of Hyde, State of South Dakota. Owned by town of Highmore. Commenced October, 1886. Completed March, 1887. Drilled by Gray Brothers, Milwaukee, Wis. Depth, 1,552 feet. Cost $7,200, or $4.64 per foot. Flow, 9 gallons per minute. Pressure, 12½ pounds per square inch when flow is shut off. Temperature of water, 73 degrees. Elevation above sea level, 1,900 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil, clay, and gravel	240	240	Blue shale	116	1,430
Blue shale	500	740	Sandstone (water, not flow)	12	1,442
Hard gray shale and iron pyrites	75	815	Sandy shale	93	1,535
Blue shale	271	1,086	Hard sand (cap rock)	2	1,537
Gray shale mixed with sand	224	1,310	Soft sandstone (flow)	15	1,552
Shale and iron pyrites	4	1,314	Bottom in sand rock.		

The top of this bore is the highest above sea level of any in the Dakota Basin. The plan of casing is the same as is used in the Miller well. There are 5 different sized casings used, the top being 6¼ inches and the bottom 3¼. Each size laps 50 feet on the lower end of the string above. Each string of casing is stopped on hard rock, except the 3¼-inch, which is 155 feet in length and reaches within 17 feet of the bottom of the bore. The lower 20 feet of this is perforated with one hundred and fifty ¼-inch holes. The flow decreased until 1890. Since that time it has been increasing a little.

Iroquois well.—Located in Sec. 6, T. 110 N., R. 58 W., town of Iroquois, county of Kingsbury, State of South Dakota. Owned by town of Iroquois. Commenced March, 1890. Completed October, 1890. Drilled by Gray Brothers, Milwaukee, Wis. Depth, 1,100 feet. Cost, $3,400, or $3.10 per foot. Flow, 100 gallons per minute. Pressure, 67 pounds per square inch when flow is shut off. Temperature of water, 73 degrees. Elevation above sea level, 1,408 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Black loam	2	2	Sand rock (very light flow)	[illegible]	[illegible]
Blue clay	[illegible]	42	Shale	[illegible]	[illegible]
Shale	[illegible]	[illegible]	Sand rock (flow)	[illegible]	[illegible]
Sand rock (very light flow)	[illegible]	[illegible]	Sand rock (no flow)	[illegible]	[illegible]
Shale	[illegible]	[illegible]	Soft rock (probably shales)	[illegible]	1,[illegible]

This bore was put down for water for domestic use and obtained a small supply of very soft water. On account of its purity it is used also for supplying the railroad with water for locomotive use. It is cased with 6-inch, 5-inch, and 4½-inch casing, the lower end of the 4½-inch casing being perforated with ¼-inch holes.

Britton well.—Located in Sec. 26, T. 127 N., R. 58 W., town of Britton, county of Marshall, State of South Dakota. Owned by town of Britton. Commenced December 1, 1888. Completed March 25, 1889. Drilled by Swan Brothers, Andover, S. Dak. Depth, 1,004 feet. Cost, $3,614, or $3.56 per foot. Flow, 600 gallons per minute. Pressure, 115 pounds per square inch when flow is shut off. Temperature of water, 64 degrees. Elevation above sea level, 1,362 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Sand (pockets of coal)	90	90	Limestone	5	880
Blue clay	25	115	Sand and shale (flow)	25	905
Blue shale	290	405	Shale, lime, coal, and pyrites	70	975
Blue shale (hard streaks)	245	650	Sandstone (flow) shale near bottom	29	1,004
Blue shale (tough)	175	825			
Sandy shale	50	875			

The water in this well is clear and soft, but when allowed to flow freely it is a little milky in appearance at first. It is used for domestic purposes and to irrigate lawns and gardens; also to drive a motor for running printing presses. It is cased with 8-inch, 6-inch, 4½-inch, and 3½-inch casing. The 3½-inch casing reaches to the top of the bore, and the lower 104 feet is perforated.

Bridgewater well.—Located in T. 101 N., R. 56 W., town of Bridgewater, county of McCook, State of South Dakota. Owned by town of Bridgewater. Commenced April 20, 1891. Completed June 2, 1891. Drilled by Col. C. H. Chandler. Depth, 229 feet. Cost, $515, or $2.25 per foot. Elevation above sea level, 1,413 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Yellow clay	30	30	Light-colored clay and bowlders	70	197
Blue clay	25	55	Quartzite (probably bowlder)	4	201
Quicksand	11	66	Soft sand rock	18	219
Hard blue clay and sand	45	111	Hard sand rock shelly bottom, 5 feet	10	229
Quicksand	12	123			
Cemented sand and gravel	4	127			

This bore was put down by the town of Bridgewater, but on account of the failure to sell the town bonds work was stopped when it reached a depth of 229 feet. A small vein of good water was found at 224 feet, which rises within 60 feet of the surface and is lifted the balance of the way by a pump. The water is used for domestic purposes. It is cased with 5½-inch, 4-inch and 2½-inch casing.

Salem well.—Situated in T. 103 N., R. 55 W., town of Salem, county of McCook, State of South Dakota. Owned by town of Salem. Completed fall of 1887. Drilled by Swan Brothers. Depth, 247 feet. Elevation above sea level, 1,517 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	2	2	Soapstone	60	215
Yellow clay	25	27	Loose sand (water rises to 75 feet of surface)	5	220
Blue clay	31	58	Blue shale	2	222
Quicksand	11	69	Sioux quartzite	25	247
Blue clay	86	155			

This bore was put down for water for town purposes, but was abandoned after drilling 25 feet into quartzite.

McCurdy well.—Located in Sec. 15., T. 106 N., R. 61 W., town of Letcher, county of Sanborn, State of South Dakota. Owned by Frank McCurdy. Commenced July 15,

1890. Completed August 13, 1890. Drilled by C. O. Hutchins, Woonsocket. Depth, 578 feet. Cost, $700, or $1.21 per foot. Flow, about 70 gallons per minute. Elevation above sea level, 1,310 feet.

Strata passed through are as follows:

	Thickness.	Total		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil and clay	30	30	Soapstone	8	514
Sand and gravel	22	52	Sand rock (small flow)	0½	514½
Blue clay	95	147	Lignite	1	515½
Gravel	1	148	Soapstone	37	552½
Chalk with cement	175	323	Sand rock (small flow)	0½	553
Limestone	7	330	Soapstone	12	565
Soapstone	100	430	Quicksand	2	567
Soapstone with thin veins of iron pyrites 2 feet to 6 feet apart	75	505	Soapstone	1	568
Sand rock (small flow)	1	506	Sand rock (water)	10	578

This is a 2-inch well put down for domestic and stock purposes. Cost as follows: Hauling water $10; fuel, $50; cost of tools and drilling, including labor, $505; total $700.

Letcher well.—Located in Sec. 15, T. 105 N., R. 61 W., town of Letcher, county of Sanborn, State of South Dakota. Owned by town of Letcher. Commenced July, 1891. Completed July, 1891. Drilled by city. Depth, 577 feet. Cost, $1,800, or $3.12 per foot. Flow, 80 gallons per minute. Pressure, 90 pounds per square inch when flow is shut off. Temperature of water, 58 degrees. Elevation above sea level, 1,300 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Shale	100	570	Sand rock (flow)	7	577

This bore was made by the town of Letcher for water for domestic purposes and for a public watering place. Although the supply is comparatively small it serves the purposes for which it was intended and has filled a natural depression in the ground adjoining the town, forming a lake of several acres. It is claimed that a similar 3-inch bore can now be put down for $500. Cased with 500 feet of 3-inch casing, which is stopped on hard rock. Inside of this is 570 feet of 2-inch pipe, which comes to the surface.

Woonsocket well.—Located in Sec. 28, T. 107 N., R. 62 W., town of Woonsocket county of Sanborn, State of South Dakota. Owned by town of Woonsocket. Completed in 1890. Drilled by Gray Brothers, Milwaukee, Wis. Depth, 725 feet. Cost, $3,820, or $5.27 per foot. Flow, 1,150 gallons per minute. Pressure, 130 pounds per square inch when flow is shut off. Temperature of water, 65 degrees. Elevation above sea level, 1,308 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil and clay	110	110	Soft sand rock (water)	41	725
Shale	240	350	The sand rock in this well was full of very hard but thin streaks, and when each hard streak was drilled through the flow increased.		
Iron pyrites (soft sand rock)	2	352			
Shale	180	532			
Hard sand rock and iron pyrites	30	562			
Shale	118	680			
Hard sand cap rock	4	684			

The flow and pressure of this well have diminished considerably since 1890. In the fall of that year the flow from the well was shut off for a short time. Upon opening it again it has failed to recover its former flow and pressure. For several days afterwards large quantities of sand, shale, and a tough, tenacious clay were thrown out of the well. It is estimated that at least 100 car loads—say 2,000 cubic yards—

of this material were brought up with the water before the flow could be shut off. But since regulating valves have been attached and the flow reduced to the actual needs of the city, the water has cleared up; but upon opening the valves prior to the time when the flow was entirely shut off sand, broken rock, and mud would be thrown out. The bore is cased to what is commonly called the cap rock, 680 feet below the surface, where the 6-inch casing is seated, which is 45 feet above the bottom of the bore. The amount of solid material thrown out (if the estimates are correct) would make a cavity at the bottom of the well equal to 38 feet cube, and it is not at all unlikely that there has been a caving in of the material overlying so large a cavity. The casing is open at its lower end, and rests upon a stratum of hard rock only 4 feet thick. The former flow was 2,750 gallons per minute and the pressure was 155 pounds per square inch. There are three or possibly four reasons that can be given as the cause of the decrease in the flow of this well. One is the probable caving in of the material overlying the cavity that undoubtedly exists after so large a quantity as 54,000 cubic feet of solid material has been removed at the bottom of the bore. Its caving in may have choked the free flow from the lower water course. The second is the probable falling down of the cap rock, on which the casing is seated, leaving a part of the flow to pass up outside of the casing. The third is the possibility of a rock having gotten fast in the lower end of the casing. The fourth is the possibility of the flow being diminished by another well about 1,500 feet distant, which was completed last fall, or about the time that this one was shut down. There are some reasons for believing that this is not the case, as the city well does not show any increase of volume or pressure when the other well is shut down for days, or even weeks, as it was during the past spring and summer. The well flows sufficient for city purposes, so there is no necessity for attempting to regain the original flow.

Mill well.—Located in Sec. 23, T. 107 N., R. 62 W., town of Woonsocket, county of Sanborn, State of South Dakota. Owned by Northey & Duncan. Completed in 1890. Drilled by Robbins & Vowe. Depth, 775 feet. Cost $4,500, or $5.80 per foot. Pressure, 125 pounds per square inch when flow is shut off. Temperature of water, 62 degrees. Elevation above sea level, 1,316 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Yellow clay	25	25	Soapstone	19	455
Blue clay	20	45	Soft shale	5	460
Sand	2	47	Soapstone iron pyrites	80	540
Blue clay	11	58	Shale and sandy shale iron pyrites	97	637
Hardpan	7	65	Hard lime rock	8	645
Sand	20	85	Shale	45	690
Hardpan and gravel	70	155	Hard rock	1	691
Shale and iron pyrites	81	236	Shale	6	697
Soapstone	176	412	Sand rock and water, stopped in sand rock	78	775
Hard sandstone	20	432			
Brown sandstone	4	436			

The pressure and flow from this well are utilized to drive a 125-barrel flour mill. The pipe connected with this well is carried underground a few hundred feet and is finally reduced to a 2-inch nozzle, which directs the stream against the periphery of a 4-foot Pelton water wheel, which develops ample power to drive the mill with all its machinery. Prior to selecting the proper sized wheel and discharge orifice, a test was made of the pressure that could be maintained with different sized opening, with the following results: The well was allowed to flow freely for forty-eight hours, and then closed, showing a pressure of 85 pounds. When discharging a 2-inch stream the pressure was 78 pounds; when discharging a 2½-inch the pressure was 72 pounds; when discharging a 3-inch stream the pressure was 62 pounds; when discharging a 4-inch stream the pressure was 48 pounds. A few hours afterwards the closed pressure was 93 pounds; with a 2-inch stream, 86 pounds. One day afterwards, when discharging a 2-inch stream, the pressure was 88 pounds. Two days afterwards, with a 2-inch stream, the pressure was 94 pounds. Three days afterwards the pressure was 96 pounds while discharging a 2-inch stream. The bore is cased with 697 feet of 7-inch casing seated on the sand rock with no inside or perforated pipe. This well is situated about 1,500 feet north from the city well. Although the two wells are so near each other it is thought that one does not interfere with the flow or pressure of the other. The proprietors have never measured the flow, nor would they consent to have it measured without a guaranty for any damage to the well that might occur in opening it for the full flow. They claim there is great danger of the well caving and choking up after it has been allowed to flow freely, as it throws up large quantities of sand and rock, the same as the city well has done.

Hines well.—Located in Sec. 33, T. 107 N., R. 62 W., town 1 mile west of Woonsocket, county of Sanborn, State of South Dakota. Owned by Charles E. Hines. Completed March, 1891. Drilled by Charles E. Hines. Depth, 742 feet. Cost, $900, or $1.20 per foot. Flow, 425 gallons per minute. Pressure, 131 pounds per square inch when flow is shut off. Temperature of water, 65 degrees. Elevation above sea level, 1,348 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Shale to		689	Sand rock flow stopped in sand rock	53	742

This well was put down for irrigation purposes. It is cased with a single string of 3-inch casing, which is seated in sand rock, in which the flow is obtained. When allowed to flow freely sand comes up with the water, especially when first opened. The pressure reaches its maximum quickly when the flow is stopped. Some irrigation was done this year from the water. The owner intends to construct a storage reservoir and put 200 acres under a complete system of irrigation next year.

Ashton well.—Located in Sec. 35, T. 118 N., R. 64 W., town of Ashton, county of Spink, State of South Dakota. Owned by Chicago, Milwaukee and St. Paul Railroad. Commenced September, 1882. Completed in 1883. Drilled by Swan Brothers, Andover, S. Dak. Depth, 925 feet. Cost, $4,000, or $4.32 per foot. Flow, 100 gallons per minute. Pressure, 60 pounds when flow is shut off. Elevation above sea level, 1,296 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Drift	66	66	Sandy shale (small flow	35	830
Black shale	34	100	Yellow limestone	30	860
Gray shale	300	400	Lime and shale	32	892
Blue shale	250	650	Iron pyrites and lime	8	900
Sandy shale (small flow)	10	660	Sandstone (main flow)	15	915
Blue shale	135	795	Blue shale	10	925

This well was put down by the railroad company for water for locomotive use, but owing to the tendency to destroy iron and foaming badly in the boilers it is not used for that purpose, and the well is practically abandoned. The pressure and flow remain the same as when first struck. It is cased with 550 feet of 6-inch casing which is seated in gray shale. Inside of this is 903 feet of 4½-inch casing, which starts from the top and reaches the lower flow. No perforations. Lower end open.

Doland well.—Located, in sec. 31, T. 117 N. R., 60 W., town of Doland, county of Spink, State of South Dakota. Owned by town of Doland. Completed in 1889. Drilled by Swan Bros., Andover, S. Dak. Depth, 897 feet. Flow, 370 gallons per minute. Pressure, 122 pounds per square inch when the flow is cut off. Temperature, 64 degrees. Elevation above sea level, 1,350 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Yellow clay	12	12	Blue shale	135	460
Black clay	30	42	Shale, sand, and lime (small flow)	96	556
Blue shale (hard)	33	75	Blue shale (lime streaks)	324	880
Blue shale (soft)	200	275	Sandstone (main flow)	15	895
Sandstone	50	325	Blue shale	2	897

This well is used for domestic purposes and for irrigating trees and lawns. It is thought the well caved in last April and has become partly choked up with mud and sand. The flow has fallen off about one-half since that time, but the pressure has increased 10 pounds and the water is 4 degrees colder. It is cased with a single string of 4½-inch casing, which is seated in the rock capping the main flow. The water is quite muddy, being probably from the disintegration of the blue shale.

Frankfort well.—Located in T. 116 N., R. 62 W., town of Frankfort, county of Spink, State of South Dakota. Owned by city of Frankfort. Completed about 1888. Drilled by Swan Bros., Andover, S. Dak. Depth, 1,008 feet. Cost, $4,032, or $4 per foot. Elevation above sea level, 1,296 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	2	2	Soapstone	96	[illegible]
Yellow clay	20	22	Conglomerate	2	[illegible]
Sand and gravel	20	42	Sand rock	67	[illegible]
Blue clay	60	102	Very hard sand rock	5	[illegible]
Soapstone	200	302	Sand rock	60	[illegible]
Bastard lime	10	312	Soapstone	20	[illegible]
Soapstone	290	602	Sand rock	40	[illegible]
Conglomerate	5	607	Soapstone	15	1,0[illegible]
Soapstone	90	697	Sand rock	8	1,0[illegible]
Sandy lime	10	707			

This bore was put down by the town of Frankfort for water for municipal purposes. Owing to a defect in casing the well, the flow comes up outside, the water being used for irrigating about 100 acres instead of supplying the town with water under pressure, as was intended. The water is hard and muddy.

Well is cased with 225 feet of 8-inch casing, inside of which is 600 feet of 6-inch, and inside of the 6-inch is 860 feet of 4½-inch. The laps are not given. It is reported that the 6-inch casing has slipped down so that its upper end is below the bottom of the 8-inch, and as the latter is seated in soapstone it is quite probable that the leak occurs at that place.

Mellette well.—Located in sec. 3, T. 119 N., R. 64 W., town of Mellette, county of Spink, State of South Dakota. Owned by town of Mellette. Commenced October 12, 1889. Completed December 24, 1889. Drilled by W. E. Swan Company, Andover, S. Dak. Depth, 920 feet. Cost, $3,100, or $3.37 per foot. Flow, 1,215 gallons per minute. Pressure, 166 pounds per square inch when flow is shut off. Temperature of water, 65 degrees. Elevation above sea level, 1,294 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Black soil	1	1	Soapstone	150	610
Yellow clay	24	25	Conglomerate	1	611
Blue clay	40	65	Soapstone	200	811
Sand and gravel	20	85	Sandy lime	10	821
Blue clay	10	95	Soapstone	20	841
Soapstone	200	295	Conglomerate	3	844
Conglomerate	5	300	Soapstone	33	877
Soapstone	150	450	Conglomerate	7	884
Bastard lime	10	460	Sand rock	36	920

This well was put down for municipal purposes, which it serves well, as it furnishes an abundant supply of clear water with a pressure in the distributing pipes for a splendid fire protection. The surplus water is used for irrigating about 100 acres of garden and farming land. It is cased with 450 feet of 6-inch casing, which is seated in limestone. Inside of this is 877 feet of 4½-inch casing, reaching from the top to the cap rock, 877 feet from the surface.

Brunn well.—Located in sec. 22, T. 119 N., R. 63 W., town 7 miles east of Mellette, county of Spink, State of South Dakota. Owned by E. Brunn. Completed December, 1890. Drilled by E. Brunn. Depth, 958 feet. Flow, 60 gallons per minute. Pressure, 141 pounds per square inch when flow is shut off. Temperature of water, 65 degrees.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil, clay, and shale	450	450	Shale (small flow)	40	920
Iron pyrites	2	452	Cap rock	2	922
Shale	48	500	Sand rock (water)	36	958
Shale (small flow)	380	880			

This well was put down for irrigation purposes, but the flow is insufficient. There is 55 feet of drill pipe, and a drill bit in the bottom of the bore. At first the flow was 160 gallons per minute but since it has decreased to 60. There is a constant flow of sand with the water. Cased with 4½-inch casing and 86 feet of 3½-inch, which is perforated.

Baker well.—Located in sec. 32, T. 119 N., R. 63 W., town of Mellette, county of Spink, State of South Dakota. Owned by J. W. Baker. Commenced February, 1891. Completed March 1, 1891. Drilled by Swan Bros., Andover, S. Dak. Depth, 920 feet. Cost, $2,760, or $3 per foot. Temperature of water, 65 degrees. Elevation above sea level, 1,275 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	2	2	Soapstone	297	700
Yellow clay	20	22	Iron pyrites	4	704
Blue clay	45	67	Soapstone	160	864
Soapstone	333	400	Iron pyrites (lime soapstone cap rock)	7	871
Iron pyrites (very light flow)	3	403	Sandstone (flow)	49	920

This well was put down for irrigation purposes and has been so used during the past summer. At the time the well was visited by us there was no way to measure its flow except to compute the discharge due to a 2½-inch opening under 34 pounds pressure, which gives 894 gallons per minute. With a free flow the discharge would probably be 1,000 gallons. The flow has increased since the well was completed. At times it throws up quantities of sand and muddy water. It has been observed that this occurs just prior to a storm or low barometer. The well is cased with 864 feet of 4½-inch casing, seated in the rock just above the main flow. Inside and at the lower end of this is 60 feet of 3-inch pipe, which laps 4 feet on the 4½-inch. The lower end of the 3-inch pipe is perforated with ½-inch holes, 12 to the foot.

Day well.—Located in sec. 23, T. 119 N., R. 64 W., town 3 miles south of Mellette county of Spink, State of South Dakota. Owned by J. P. Day. Commenced March 1, 1891. Completed May 1, 1891. Drilled by Swan Brothers, Andover, S. Dak. Depth 993 feet. Cost, $3,070, or $3.10 per foot. Flow, 1,300 gallons per minute. Pressure 135 pounds per square inch when flow is shut off. Temperature of water, 65 degrees. Elevation above sea level, 1,285 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet*
Soil	1	1	Soapstone (very small flow)	100	800
Yellow clay	15	16	Rotten limestone	20	820
Blue clay	20	36	Soapstone	60	880
Sand and gravel	36	72	Iron pyrites	2	882
Soapstone	350	422	Soapstone	26	908
Iron pyrites and lime	3	425	Iron pyrites and lime cap rock	7	915
Soapstone	275	700	Sand rock (flow)	78	993

This well was put down for irrigation purposes. I was unable to obtain a full free flow; with a 2-inch opening the pressure was 95 pounds; with a 4-inch opening the pressure was 37 pounds; with two 4-inch openings, one of them leading through 300 feet of pipe, the flow by weir measurement was 1,300 gallons per minute, with a pressure of 12 pounds at the top of the well. When first completed there were large quantities of clear pure sand thrown out with the water. It is estimated that at least 100 cubic yards per hour were thrown out during the first two or three days. This well was put down in thirty days. Cost as follows: Derrick, material, hauling, and labor, $130; hauling water, $90; fuel, including hauling, $210; casing, $600; labor in drilling, $1,920; board of men, $120; total, $3,070. The well is cased with 910 feet of 6-inch casing, which is seated in the cap rock. Inside of this is 96 feet of 4½-inch casing, which laps the lower end of the 6-inch casing 14 feet and which is perforated. About 200 acres have been irrigated this season without the aid of storage reservoirs. At times the water had to be shut off to prevent the flooding of the country.

Bird well.—Located in sec. 19, T. 119 N., R. 63 W., town of Mellette, county of Spink, State of South Dakota. Owned by Rowbotham, Bird, and Moore. Commenced August 6, 1891. Completed September 1, 1891. Drilled by Swan Company.

Depth, 936 feet. Cost, $2,466, or $2.65 per foot. Flow, 870 gallons per minute. Pressure, 158 pounds per square inch when flow is shut off. Temperature of water, 65 degrees. Elevation above sea level, 1,280 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	2	2	Sulphate of iron	2	711
Yellow clay	30	32	Soapstone	181	[illegible]
Black clay	42	74	Bastard lime	8	[illegible]
Soapstone	375	449	Conglomerate	2	[illegible]
Conglomerate	10	459	Sand rock	28	[illegible]
Soapstone	250	709			

This well is owned by three farmers whose land adjoins each other. The water is used for irrigation purposes; each owns 160 acres. The water is divided by taking water from the well with three pipes of equal size. The well is cased with 100 feet of 6-inch casing starting from the top and seated on the cap rock. Inside of this is 900 feet of 4½-inch casing with 20 feet lap. Inside of this at the bottom is 60 feet of 3-inch casing. Below the lap the 3-inch casing is perforated with ¼-inch holes, 8 to the foot. Cost as follows: Hauling derrick material and erecting, $56; hauling water, $90; fuel, including hauling, $120; pipe and hauling, $607.50; labor in drilling and board of men, $1,592.50; total, $2,466. In connection with this well two 4-acre reservoirs had to be built. When done it is expected the well will supply water for 480 acres of land.

Redfield well.—Located in sec. 10, T. 116 N., R. 64 W., town of Redfield, county of Spink, State of South Dakota. Owned by town of Redfield. Completed in 1886. Drilled by Gray Brothers, Milwaukee, Wis. Depth, 964 feet. Cost, $2,990, or $3.10 per foot. Flow, 1,260 gallons per minute. Pressure, 177 pounds when flow is shut off. Temperature of water, 64 degrees. Elevation above sea level, 1,300 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil and clay	140	140	Shale	150	941
Shale	610	750	Hard sand rock iron pyrites cap	3	944
Sand rock (small flow)	1	751	Sand rock (flow)	20	964
Shale and iron pyrites	40	791	Bottom in sand rock		

This well was put down for water for municipal purposes. After supplying the needs of 2,000 people, the surplus is used for irrigation of lawns and market gardens. This is a high-pressure well, with pressure and volume sufficient to throw an inch and a half stream 130 feet high. Water clear and soft. Is cased with 480 feet of 6¼-inch casing seated in shale; then 501 feet of 5$\frac{3}{16}$-inch casing which laps 40 feet on the outside casing. This is seated in the cap rock 941 feet from the surface; then there is 53 feet of 4½-inch, which laps 30 feet of the 5$\frac{3}{16}$-inch; this is perforated below the lap with ¼-inch holes, 12 to the foot.

Hall well.—Located in T. 117 N., R. 64 W., county of Spink, State of South Dakota. Owned by J. F. Hall. Completed October 24, 1891. Drilled by Swan Brothers, Andover, S. Dak. Depth, 987 feet. Cost, $2,500, or $2.53 per foot. Elevation above sea level, 1,302 feet (approximately).

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	2	2	Soapstone	40	[illegible]
Yellow clay	45	47	Bastard lime	5	[illegible]
Blue clay	40	87	Soapstone	34	[illegible]
Light soapstone	238	325	Conglomerate	5	[illegible]
Dark soapstone	250	575	Sand rock	40	[illegible]
Conglomerate	3	578	Lime and sand mixed	3	[illegible]
Dark soapstone	162	740	Sand rock	20	[illegible]
Iron pyrites	1	741	Lime rock	5	[illegible]
Soapstone	60	801	Sand rock	20	[illegible]
Conglomerate	5	[illegible]	Conglomerate	10	[illegible]

This well was put down for irrigation purposes and was finished after field work was completed. Reported to have a good flow of water. Pressure and amount of flow have not been measured.

Fort Sully well.—Located in T. 113 N., R. 81 W., town of Fort Sully, county of Sully, State of South Dakota. Owned by the United States Government. Commenced fall of 1884. Not completed. Drilled by Aurora Well Company. Depth, 979 feet. No record of strata kept.

This bore was put down by the United States War Department for water to supply the post at Fort Sully. The postmaster at this place writes that "three years were spent on the job, when it was abandoned at the depth of 979 feet in a bed of quicksand." No record of the strata passed through in this bore is obtainable.

Fort Randall well.—Located in sec. 17, T. 95 N., R. 65 W., town of Fort Randall, county of Todd, State of South Dakota. Owned by United States Government. Commenced December 5, 1885. Completed January 25, 1886. Depth, 610 feet. Cost, $2,578, or $4.22 per foot. Flow, 600 gallons per minute. Temperature of water, 80 degrees. Elevation above sea level, 1,245 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Gumbo and blue clay	100	100	Blue clay	56	576
Soft stones	360	460	Hard rock	34	610
Water-bearing sandstone	60	520			

This well was put down by the United States War Department for the use of the post at Fort Randall. The water is reported to be unfit for domestic purposes, but is used for supplying a swimming-tank, flushing sewers, fire protection, and a little is used for irrigation. Fine white sand constantly comes up with the water. The bore is cased with 100 feet of 6-inch casing and 576 feet of 4-inch, both strings coming to the surface. The mineral in the water has so destroyed the casing as to allow the flow to come up on the outside of the pipe, which has washed out a hole 20 feet in diameter and 60 feet deep. It is intended, if possible, to stop the flow.

Mill well.—Located in Sec. 7, T. 93 N., R. 55 W., town of Yankton, county of Yankton, State of South Dakota. Owned by Miner & Walker. Completed in 1883. Drilled by Carr & Ritchie. Depth, 505 feet. Cost, $2,500, or $4.95 per foot. Flow, 1,450 gallons per minute. Pressure, 48 pounds per square inch when the flow is shut off. Temperature of water, 62 degrees. Elevation above sea level, 1,190 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil, sand, and gravel	38	38	Sand	25	254
Chalk rock	62	100	Shale	125	379
Shale	26	126	Sand and clay (alternate water in sand)	106	485
Hard rock	4	130	Water-bearing sand	106	505
Sand	34	164			
Shale	65	229			

The water from this well is used to drive a 45-barrel roller flour mill. Twenty-seven horse power is developed by a Dubuque turbine water wheel. The flow is said to be decreasing a little. When first struck it was 2,000 gallons per minute. Last year it was 1,680; this year 1,450. The bore is cased with 500 feet of 6-inch casing, which is seated in a water-bearing rock.

Wilcox well.—Located in T. 93 N., R. 55 W., town of Yankton, county of Yankton, State of South Dakota. Owned by R. P. Wilcox. Commenced winter of 1890. Completed in winter of 1890. Depth, 455 feet. Cost, $450, or $1 per foot. Flow, 350 gallons per minute. Pressure, 55 pounds per square inch when flow is shut off. Temperature of water, 60 degrees. Elevation above sea level, 1,168 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil and clay			Water-bearing sand rock	33	455
Shale	125				

This bore reaches one of the upper flows only. The water is used for stock purposes, but the owner intends hereafter to use it for irrigation. Water hard, but clear. The pressure runs up quickly to 55 pounds after the flow is shut off; it is cased with a single string of 3-inch casing to 432 feet.

Cement-works well.—Located in T. 93 N., R. 56 W.; town 4 miles west of Yankton, county of Yankton, State of South Dakota. Owned by Western Portland Cement Company. Commenced fall of 1890. Completed fall of 1890. Drilled by Gray Brothers, Milwaukee, Wis. Depth, 500 feet. Cost, $2,500, or $5 per foot. Flow, 1,300 gallons per minute. Pressure, 50 pounds when flow is shut off. Temperature of water, 64 degrees. Elevation above sea level, 1,200 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil and clay	140	140	Sand rock (small flow)	3	408
Blue shale	235	375	Shale	27	435
Sand rock (small flow)	2	377	Sand rock (small flow)	1	436
Shale	13	390	Shale, sandy	14	450
Sand rock (small flow)	1	391	Soft sand rock and water	50	500
Shale	14	405			

The water from this well is used for mixing and preparing the raw materials used in the manufacture of cement. It is cased with 450 feet of 6-inch casing and 70 feet of 5-inch, which laps 20 feet on the 6-inch casing. The lower end of the 5-inch is perforated with ½-inch holes.

Asylum well.—Located in T. 93 N., R. 55 W., town of Yankton, county of Yankton, State of South Dakota. Owned by State of South Dakota. Completed in 1887. Depth, 672 feet. Cost, $2,860, or $4.28 per foot. Flow, 165 gallons per minute. Pressure, 10 pounds per square inch when flow shut is off. Temperature, 64 degrees. Elevation above sea level, 1,285 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Yellow clay	25	25	Shale	300	415
Blue clay	30	55	Sand and clay	185	600
Chalk	60	115	Water-bearing sand	72	672

The water is used to supply 200 people in the asylum and for irrigating 2 acres of lawn. The water is hard, but clear. The well is cased with 4½-inch casing, which is seated in the cap rock. The elevation of this well being greater than the others in Yankton, the pressure at the surface is consequently less. The hydrostatic elevation, due to the 10-pound pressure, of this well is 1,308 feet. That due to the city and mill wells is 1,301 feet each, which shows a remarkable uniformity in the hydrostatic pressure of these three wells.

City well.—Located in Sec. 7, T. 93 N., R. 55 W., town of Yankton, county of Yankton, State of South Dakota. Owned by city of Yankton. Commenced fall of 1881. Completed spring of 1882. Drilled by Carr & Ritchie. Depth, 615 feet. Cost, $2,800, or $4.55 per foot. Flow, 880 gallons per minute. Pressure, 18 pounds per square inch when flow is shut off. Temperature of water, 62 degrees. Elevation above sea level, 1,259 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Yellow clay	25	25	Shale	300	415
Blue clay	30	55	Sand and clay	195	610
Chalk	60	115	Water-bearing sand	5	615

The water from this well is used for municipal purposes. It was one of the first artesian wells put down in this section. Its flow has decreased but very little; quality hard, but clear. When it has been flowing freely for some time it reaches its maximum pressure in one hour after being shut down. There is only one string of 6-inch casing, which is seated in the sand rock.

Court well.—Located in Sec. 11, T. 140 N., R. 55 W.; town 2½ miles northwest of Buffalo, county of Cass, State of North Dakota. Owned by H. E. Sargent. Completed in summer of 1889. Drilled by George Frazer. Depth, 600 feet. Cost, $3,200, or $5.33 per foot. Flow, 12 gallons per minute. Pressure, 45 pounds per square inch when flow is shut off. Temperature of water, 52 degrees. Elevation above sea level, 1,190 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil and clay loam	15	15	Clay marl	250	[illegible]
Clay	185	200	Vein water	1	[illegible]
Marl	100	300	Clay marl	49	[illegible]

This well is situated on the table-lands between James River and the Red River of the North. The drainage at this point is into the Red River, whose waters finally reach the sea at Hudson Bay. Although this locality is near the continental divide, its elevation above the sea is little less than 1,200 feet. The log of this bore and the next two succeeding ones show very different formations from those which occur in the James River Basin, as shown by the logs of the preceding seventy-five bores, the most notable difference being the absence of solid rock. The whole material penetrated thus far in this vicinity indicates that it is a deep deposit of alluvial matter in a lake which at one time existed in this section. Deep bores might reveal the existence of a lower formation of rocks similar to those found to the west and south, but to our knowledge none have been made deep enough to determine this question. The water from this well is a little salty. It is used for stock purposes. The bore is cased with 150 feet of 3-inch casing, 250 feet of 2-inch, and 550 feet of 1¼-inch. All of these start from the top.

Staples well.—Located in Sec. 12, T. 140 N., R. 54 W.; town 6 miles northeast of Buffalo, county of Cass, State of North Dakota. Owned by Staples. Completed Summer of 1889. Depth, 514 feet. Cost, $1,500, or $2.92 per foot. Flow, 25 gallons per minute. Pressure, 50 pounds per square inch when flow is shut off. Temperature of water, 51½ degrees. Elevation above sea level, 1,170 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	3	3	Blue clay	177	[illegible]
Blue clay	300	303	Layers of clay and holes (no sand)	14	[illegible]
Black shale	20	323			

The quality of water from this well is good. It is used for watering stock and for household purposes. It has a continuous and free discharge, but on stopping the flow the pressure runs up quickly to 50 pounds per square inch. It is cased with 180 feet of 2-inch casing and 514 feet of 1¼-inch, which starts from the top. On the lower end of this is 7 feet of wire screen, made of four thicknesses of wire netting.

Tower City.—Located in Sec. 19, T. 140 N., R. 55 W., town of Tower City, county of Cass, State of North Dakota. Owned by Northern Pacific Railroad Company. Commenced fall of 1881. Completed June, 1882. Drilled by Charles Pessold. Depth, 716 feet. Cost, $3,200, or $4.47 per foot. Flow, 20 or 25 gallons per minute. Pressure, 53 pounds per square inch when flow is shut off. Temperature of water, 57 degrees.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	3	3	Flowing sand; had to mix with sand to get it out	100	[illegible]
Yellow clay	30	33	Hardpan, gravel, and rocks	[illegible]	[illegible]
Blue clay	60	93	Broke through into flowing water.		
Blue clay (sticky)	327	420			
Soft gray sand rock	74	494			
Clay getting softer	116	[illegible]			

This bore was put down by the Northern Pacific Railway Company. The flow from this well supplies a public watering place for the town. It is cased to 420 feet with 6-inch casing. Inside of this is a string of 4½ inch, which reaches from the top to the bottom of the bore. The water is hard and contains some minerals. The pressure reaches 40 pounds instantly and 53 pounds in half an hour after being closed. The elevation due to the pressure of this well and the two preceding ones is almost exactly the same, namely 1,291 feet, which is 139 feet below the surface of Devils Lake, which is 80 miles to the northwest. There are not a sufficient number of borings in this part of the country to determine the extent and direction of the dip and other features of the Tower City artesian basin. It is not difficult to find a large number of small lakes and running streams of water that have an elevation sufficiently above the top of these wells to give the pressure they have. If the other conditions are favorable to transmit the water on the surface to these wells, it is comparatively easy to account for the water supply for this basin. The James River, even at its lowest elevation in North Dakota, is high enough to supply the pressure that the water has in this basin.

Bismarck well.—Located in Sec. 4, T. 138 N., R. 80 W., town of Bismarck, county of Burleigh, State of North Dakota. Owned by city of Bismarck. Drilled by Swan Brothers, Andover, S. Dak. Completed in 1883. Depth, 1,315 feet. Elevation above sea level, 1,756 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil and yellow clay	70	70	Blue shale	104	[illegible]
Lime rock	5	75	Black sandy shale	55	[illegible]
Blue shale	25	100	Blue lime rock	5	[illegible]
Black sandy shale	25	125	Black sandy shale	60	[illegible]
Blue shale	55	180	Gray soapstone	273	[illegible]
Black shale	5	185	Blue lime rock	8	[illegible]
Bright green shale	5	190	Soapstone	346	1,260
Blue sandy shale	100	290	Iron pyrites and lime	10	1,2[illegible]
Brown shale	16	306	Soapstone	65	1,315

This bore was put down for obtaining a water supply for the city of Bismarck. The top of the bore is 140 feet above low water in the Missouri River at this place. No flow was obtained at a depth of 1,315 feet. Work was stopped at this point with the supposition that the bore was deep enough to reach the James River artesian water-bearing rock, if such existed at Bismarck. Comparing the log of this bore with those in the Dakota basin, and also comparing the elevation of the surface and the bottom of the nearest artesian wells to the eastward, which are at Devils Lake and Jamestown, it will be seen that this bore should have been carried down at least 500 feet farther to reach the same rock. The bottom of the Jamestown well, 100 miles east, is 85 feet below sea level, while the bottom of this bore is 441 feet above, making 526 feet yet to go to reach the flow, providing it is in the same horizon here as at Jamestown. From a study of the general inclination of the Dakota rock the probability is that it is still lower at Bismarck. This bore is cased with 8-inch casing to 505 feet. Inside of this is a string of 900 feet of 6-inch. Below this the bore is 4½ inches in diameter. No flows coming to the surface were found.

Ellendale well.—Located in Sec. 19, T. 129 N., R. 63 W., town of Ellendale, county of Dickey, State of North Dakota. Owned by town of Ellendale. Commenced December, 1885. Completed April 6, 1886. Depth, 1,087 feet. Drilled by Gray Brothers. Cost, $4,440, or $4.08 per foot. Flow, 700 gallons per minute. Pressure, 115 pounds per square inch when flow is shut off. Temperature of water, 69 degrees. Elevation above sea level, 1,463 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil and yellow clay	25	25	Hard sandstone cap	7	1,042
Blue clay	85	110	Soft sandstone (flow)	45	1,087
Shales	925	1,035	Bottom in sand rock		

This well was put down for municipal purposes, and obtained a good flow and pressure for fire protection and for the supply of 800 people, besides having sufficient water for irrigating lawns and a 30-acre market garden. When the flow is shut off the pressure rises quickly to 80 pounds and in a few hours it reaches its maximum, 115 pounds. The temperature of the water is above the average in the Dakota basin. The water is soft and contains a little soda and magnesia. The well is cased with 1,037 feet of 4½-inch casing and 75 feet of 3½-inch, with a lap of 25 feet. The lower end of 3½-inch is perforated with ½-inch holes, 12 to the foot.

Jones well.—Located in Sec. 10, T. 129 N., R. 63 W., town 2 miles west of Ellendale, county of Dickey, State of North Dakota. Owned by W. H. Jones. Commenced April 6, 1891. Drilled by A. T. Hayman.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil, sand, and clay	100	100	Iron pyrites and lime	1	[illegible]
Gray shale	400	500	Sandstone (soft water rose 515 feet)	2	[illegible]
White clay and lime	22	522	Clay marl	65	[illegible]
			Shale	15	

This bore was abandoned at 612 feet on account of getting the drilling tools fastened.

Oakes well.—Located in town of Oakes, county of Dickey, State of North Dakota. Owned by city of Oakes. Completed March, 1890. Drilled by Swan Brothers. Depth, 977 feet. Flow, 817 gallons when not clogged. Pressure, 125 pounds per square inch when flow is shut off. Temperature of well, 62 degrees. Elevation above sea level, 1,319 feet.

The strata passed through were as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Sand and gravel	65	65	Sand shale	25	[illegible]
Bowlder clay	15	80	Sticky shale	30	[illegible]
Blue clay	65	145	Sand shale	20	[illegible]
Blue shale	155	300	Sticky shale	35	[illegible]
Hard streak lime	1	301	Sand rock (hard)	5	[illegible]
Blue shale	99	400	Brown shale and sand rock	25	[illegible]
Hard streak lime	2	402	Lime and iron pyrites in streaks	5	[illegible]
Blue shale	128	530	White sand rock, streaks, lime, and shale	62	[illegible]
Shale and hard streak lime	45	575	White sand	19	[illegible]
Black shale	125	700	Streaks, lime, and sand	25	[illegible]
Blue shale	20	720			

This well was put down for water for public use. A great deal of sand continued to come up with the water until last winter, when it became choked up and stopped flowing, by reason of shutting off the water long enough to allow the sand in the casing and that in the bottom of the well to settle around the lower end of the pipe. The flow was partially started this summer, but only a part of the former flow was regained. It is believed when the well is finally cleaned of sand the former flow will be obtained.

Mandan well.—Located in Sec. 27, T. 139 N., R. 81 W., town of Mandan, county of Morton, State of North Dakota. Owned by city of Mandan. Commenced June, 18 Drilled by Gray Brothers, Milwaukee, Wis. Elevation above sea level, 1,645 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
River deposit (sand)	90	90	Close sand rock (flow)	60	[illegible]
River deposit (gravel)	5	95	Shale changing some in color but not in hardness, mixed badly	1,[illegible]	1,[illegible]
Gray shale	25	120	White marl (harder than shale, but no grit)		
Sand rock (small flow)	5	125			
Gray shale	285	410			

This bore is being put down by the city of Mandan, who have made contract to put down 2,000 feet. Cost when finished, $10,000. December 12, the depth was 1,590 feet and drilling in shale. It is cased with 10-inch casing to 180 feet; then with 8-inch to 480 feet; then with 6-inch to 960 feet; then with 5 inch to the bottom, 1,590 feet. All the casings come to the top.

Hamilton well.—Located in sec. 35, T. 162 N., R. 53 W., town of Hamilton, county of Pembina, State of North Dakota. Owned by Hamilton Artesian Well Company. Commenced November, 1887. Completed August, 1889. Drilled by W. B. Clements, Cavalier, N. Dak. Depth, 1,560 feet. Cost, $10,150, or $6.50 per foot. Flow, 26 gallons per minute. Pressure, 27 pounds per square inch when flow is shut off. Temperature of water, 41½°. Elevation above sea level, 894 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	10	10	Gray limestone	277	584
Blue clay	122	132	Pink limestone	25	609
Coarse sand (surface water)	42	174	Gray limestone (very soft)	153	762
Hard pan (cemented gravel)	15	189	Blue shale (caving)	130	892
Quicksand	4	193	White sandstone	5	897
Red shale	32	225	Blue granite	344	1,241
Blue shale	20	245	White sand (main flow)	1½	1,242½
Red shale	43	288	Blue granite	1½	1,244
Gray limestone	12	300	White sandstone	316	1,560
Blue shale (flow)	7	307			

This bore was put down for a test well, and with the hope of obtaining a supply of water for city purposes. Two small flows of salt water were struck, one at 300 feet which flowed 90 gallons per minute, the other at 1,241, which flowed at first 45 gallons of brine per minute. The discharge is now 26 gallons per minute through 300 feet of three-fourths inch pipe, with a pressure of 12 pounds to the square inch. The water contains 2,000 grains of salt per gallon. The bore is cased with 6-inch casing to 350 feet. Inside of this is a string of 897 feet of 4-inch, which starts from the top. There are 600 feet of drill poles, and a drill in the bottom of this bore. The lower 350 feet is in what is supposed to be Laurentian granite. The bottom of this bore is 736 feet below the level of the sea.

Devils Lake well.—Located in sec. 34, T. 154 N., R. 64 W., town of Devils Lake, county of Ramsey, State of North Dakota. Owned by city of Devils Lake. Commenced July, 1888; completed July, 1889. Drilled by Swan Brothers, Andover, S. Dak. Depth, 1,520 feet. Cost, $9,000, or $6 per foot. Flow, 83 gallons per minute. Pressure, 90 pounds per square inch when flow is shut off. Temperature of water, [illegible] degrees. Elevation above sea level, 1,473 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soft shales and soapstone	1,010	1,010	Black sandy shale (streaks sand)	[illegible]	1,438
Hard gravel and sand	2	1,012	Iron pyrites	3	1,441
Black sandy shale (hard streak)	[illegible]	[illegible]	Loose sand rock (water)	[illegible]	[illegible]

This bore was made for obtaining water for municipal purposes. The lower 80 feet is in a very soft light-colored sand, which can hardly be called a rock, it being so soft as to cave in, while the bore was being made, so rapidly as to make farther progress in drilling almost impossible. It is reported that for a short time an immense flow of sand and water came up with tremendous force, but after a little it suddenly dropped down to about 80 gallons per minute with a closed pressure of 90 pounds per square inch. During the first year considerable clean, sharp, whitish sand came up with the water. During the last year the sand has nearly all disappeared, and the flow has increased 3 gallons per minute. The water flows into a tank for public use. The well is cased with 8-inch casing to 158 feet. Inside of this is a string of 650 feet of 6-inch, which starts from the top; inside of the 6-inch casing is a string of 4½-inch, 798 feet in length. At the lower end of this is 20 feet of 3½-inch, which is seated in hard sand rock. Then inside of this is 1,500 feet of 3-inch, which reaches from the top to within 20 feet of the bottom of the bore. The lower end of this pipe is plugged.

and the sides of the pipe are slitted with five or six slits, each 1 foot long, which are probably not over one-fourth of an inch wide, and through which all the water must pass into the pipe. The plugging and slitting of the pipe was done with the pipe in its present position. This slitting was done to prevent sand getting into the pipe. There are indications (judging from the operations of this well while being bored) of a much larger flow and greater pressure than is exhibited by this well. The following is an analysis of the water, by Prof. James A. Dodge, of the University of Minnesota:

	Grains per United States gallon.
Sulphate of sodium	94.[illegible]
Chloride of sodium	86.[illegible]
Carbonate of sodium	41.11
Carbonate of potassium	6.[illegible]
Carbonate of lithium	.[illegible]
Carbonate of calcium	1.[illegible]
Carbonate of magnesium	1.[illegible]
Carbonate of iron	.[illegible]
Silica	.[illegible]
Borates	Trace.
Bromides	Trace.
Organic matter	Trace.
Total of dissolved solids	[illegible]

Gases, none, except carbonic acid gas in moderate quantity, holding in solution the carbonates of calcium, magnesium and iron; hardness of water, 3¼ degrees; reaction, alkaline; color, none; odor, none; taste, somewhat brackish.

Jamestown well.—Located in sec. 36, T. 140 N., R. 64 W., town of Jamestown, county of Stutsman, State of North Dakota. Owned by city of Jamestown. Commenced October, 1886. Completed April 4, 1887. Depth, 1,476 feet. Cost, $6,700, or $4.54 per foot. Flow, 460 gallons per minute. Pressure, 97 pounds per square inch when flow is shut off. Temperature of water, 76°. Elevation above sea level, 1,391 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil, clay, and gravel	130	130	Sand rock (small flow)	10	1,[illegible]
Light shale	[illegible]	1,[illegible]	Shale and iron pyrites	[illegible]	1,[illegible]
Blue shale (hard streaks iron pyrites)	275	1,[illegible]	Hard sand rock (dry)	[illegible]	1,[illegible]
Sandy shale	65	1,[illegible]	Soft sand rock (flow)	12	1,4[illegible]

This bore was put down by the city of Jamestown for municipal purposes. During the last year the flow of this well has diminished a few gallons, but the pressure has increased. The pressure reaches its maximum instantly when the flow is shut off. This well is cased with five different sized casings, as follows: 570 feet of 6¼-inch; 495 of 5$\frac{3}{16}$-inch; 400 feet of 4½-inch; 165 feet of 3½-inch; 30 feet of 3¼-inch. The latter has a lap of 4 feet; all the others lap 40 feet. The 3¼-inch casing is perforated with one-half inch holes 16 to the foot. The bottom of this bore penetrates 16 feet into a soft sand rock and is 85 feet below sea level. Considerable gas was found while making the bore, which came up with the water in such quantity as to support a flame several feet high at the top of the casing. Probably it would still continue to come up if the well was allowed to flow without pressure.

Asylum well.—Located in sec. 6, T. 139 N., R. 63 W., 3 miles southeast of Jamestown, county of Stutsman, State of North Dakota. Owned by the State of North Dakota. Commenced summer, 1889; completed November, 1890. Drilled by Gray Brothers, Milwaukee, Wis. Depth, 1,584 feet. Cost, $7,000, or $4 per foot. Flow about 4 gallons per minute. Pressure, 70 pounds when flow is shut off. Elevation above sea level, 1,470 feet.

Strata passed through are as follows:

	Thickness.	Total.
	Feet.	*Feet.*
Soil	2	2
Red clay	40	42
Fire clay (not pure)	49	91
Quicksand and limestone bowlders (some lignite)	20	111
Shale with limestone gravel	110	221
Light-colored shale	150	371
Dark-colored shale	200	571
Light and dark shale, streaks limestone	398	969
Sandy shale	40	1,009
Sand	10	1,019
Blue shale (hard streaks limestone)	280	1,299
Quicksand, streaks shale and limestone	175	1,474
Hard sand rock	7	1,481
Soft sand rock (water)	3	1,484
Hard sand rock, iron pyrites	10	1,494
Soft sand rock (water)	11	1,505
Solid limestone	19	1,524

This bore was put down by the State of North Dakota for water for the use of the State Insane Asylum. The flow was at first about 200 gallons per minute. The soft sand rock found at 1,494 feet is caving in, and on July 8 the bottom of the bore had filled up 40 feet with sand. It is quite probable, if this was taken out, the flow would be restored. The well is cased, as follows: 900 feet of 8-inch, 550 feet of 5-inch, which laps 150 feet on the 8-inch; 250 feet of 4-inch, which laps 100 feet on the 5-inch; 100 feet of 3½-inch, which laps 50 feet on the 4-inch. The lower end of the 3½-inch is open with no perforations. The bottom of this bore is 19 feet into a solid lime rock. This rock does not appear in the city well, about 2 miles distant. The lower end of the bore is 54 feet below sea level or 31 feet above the bottom of the city well. At 1,200 feet a bed of mussel shells was passed through. The following is an analysis of the water by Erastus G. Smith, professor of chemistry, Beloit College.

Name of compound.	Symbol.	Grains per United States gallon (231 cubic inches).
Sodium sulphate	Na_2SO_4	86.15
Sodium chloride	$NaCl$	21.34
Sodium phosphate	Na_3PO_4	Trace.
Magnesium chloride	$MgCl_2$	1.36
Magnesium carbonate	$MgCO_3$	2.99
Calcium carbonate	$CaCO_3$	8.44
Alumina	Al_2O_3	.21
Iron oxide	Fe_2O_3	.12
Silica	SiO_2	.66
Total		[illegible]

From the above analysis it appears that the markedly saline taste of the water is due to—

Sodium sulphate.
Sodium chloride.
Magnesium chloride.

The water will produce, probably, marked laxative effects, especially to those not accustomed to its use. I should hesitate to use it as a boiler water, unless no other is to be had; and even then care should be used in selecting a proper scale compound.

The water is quite free from organic matters.

Grafton well.—Located in sec. 13, T. 157 N., R. 53 W., town of Grafton, county of Walsh, State of North Dakota. Owned by town of Grafton. Commenced February 24, 1885. Completed June 20, 1885. Drilled by Swan Bros., Andover, S. Dak. Depth, 912 feet; cost, $3,800, or $4.16 per foot; flow, 600 gallons per minute; pressure, 18 pounds per square inch when flow is shut off; temperature of water, 46 degrees; elevation above sea level, 825 feet.

The strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	3	3	Red shale	9	342
Yellow clay	10	13	Lime rock (gray)	4	346
Blue clay	90	103	Red shale and lime streaks	42	388
Gravelly clay (blue)	30	133	Green shale (brine flow)	2	390
Quicksand (clayey)	22	155	Gray lime-rock (gritty)	5	395
Hardpan	40	195	Magnesian lime-rock	200	595
Sand and gravel (white light flow)	30	225	Cream-colored lime-rock	105	700
Sand (coarse white)	20	245	Red shale and lime-rock	45	745
Red shale rock	10	255	Blue shale	135	880
Lime rock (reddish)	2	257	Red shale (gritty)	20	900
Redshale	13	270	Sand and quartz (white)	3	903
White sand rock (flow of water)	60	330	Granite (gray)	9	912
Blue shale	3	333			

This well was put down for municipal purposes. The water, being salty, is not suitable for domestic use, although used for watering stock and for fire purposes, and for sprinkling streets. No flows were found below 390 feet, and the bore was purposely filled up to this point. When allowed to flow freely, considerable sand is thrown up. The water contains 240 grains of salt per gallon, with a small amount of Epsom salts. The well is cased with 160 feet of 8-inch casing and 290 feet of 6-inch. The latter starts from the top and is seated in the sand-rock 100 feet above the lower flow. The lower end of the bore penetrates 9 feet into gray granite. Just above this is a 3-foot stratum of sand and quartz rock. It will be observed that all the salt-water wells have a low temperature.

Moorhead well.—Located in sec. 8, T. 139 N., R. 48 W., town of Moorhead, county of Clay, State of Minnesota. Owned by city of Moorhead. Commenced February 23, 1889. Completed October 21, 1889. Drilled by Gray Bros., Jamestown, N. Dak. Depth, 1,901 feet. Cost, $10,000, or $5.25 per foot. Elevation above sea level, 901 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Black soil	2	2	Alternating layers blue, red, and gray rock; blue not hard, red harder, and gray very hard: changes every 30 or 40 feet	725	1,200
Yellow loam	3	5	Quicksand, broken lignite	3	1,203
Yellow clay	60	65	Soft sand-rock, light-colored	27	1,230
Brown clay (sticky, tough)	45	110	Soapstone, strong fish odor	30	1,260
Hard gravel (water)	10	120	Coarse sand-rock	10	1,270
Coarser gravel (water nearly to surface)	15	135	Hard sand-rock	30	1,300
Coarse gravel, sand, and clay	60	195	Iron pyrites and lime	1	1,301
Granite bowlder	5	200	Hard blue rock (Laurentian granite)	600	1,901
Clay, with bowlders	20	220			
Dark clay	20	240			
Dark bluish clay	60	300			
Quicksand (water)	70	370			
Blue shale and quartz sand	105	475			

This bore is just across the Red River from Fargo. It was put down by the city of Moorhead for a test well, with the hope of obtaining a supply of domestic water for municipal purposes. The bottom of this bore is 1,000 feet below the level of the sea, and penetrates the granite 600 feet. The first vein of water, which was struck at 120 feet, came within 3 feet of the top of the bore. When the second flow was struck the water receded to 200 feet from the surface; when the third flow was struck at 960 feet, the water rises again within 50 feet of the surface. This bore is cased with 800 feet of 8-inch casing, and inside of this is 1,265 feet of 4½-inch, which starts from the top and is seated in hard sand-rock. Although it is not a flowing well, all the water found is artesian, but of a negative character.

Chinook well.—Town of Chinook, county of Choteau, State of Montana. Owned by C. Artesian Company. Commenced July, 1890. Drilled by hired employés. Depth, 960 feet; cost, $4,490, or $4.70 per foot. Temperature of water, 40 degrees. Elevation above sea level, 2,404 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Loam and sand	112	112	Blue clay, interspersed with thin strata lime and sandstone, soft mud	200	820
Stone bowlders	12	124	Blue clay, with gas and petroleum	6	826
Stiff clay	96	220			
Sandstone	2	222			
Blue clay	318	540			
Sandstone	1½	541½			
Blue clay	78½	620			

This bore was put down to its present depth by the town of Chinook, Mont. Owing to some uncertainty regarding the title and ownership of the land on which the bore was being made, work has been suspended until the title can be perfected. Data relative to this bore was obtained by correspondence, which states that four flows were struck at 112, 220, 540, and 620 feet from the surface. The supposition is that at those depths are veins of water which are probably artesian in their character, but not of sufficient force to flow over the top of the bore. The two lower veins are reported to be salty.

Beck well.—Located in sec. 34, T. 8 S., R. 47 E., town of Miles City, county of Custer, State of Montana. Owned by O. C. Beck. Commenced June, 1886. Completed June, 1886. Drilled by O. C. Beck. Depth, 456 feet; cost, $575, or $1.26 per foot. Flow, 5 gallons per minute. Pressure, 7 pounds per square inch when flow is shut off. Temperature of water, 57 degrees. Elevation above sea level, 2,358 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Adobe soil and subsoil	19	19	Slate and sand-rock (mixed)	185	250
Gravel	21	40	Sand-rock (two light flows)	50	300
Hard sand-rock	2	42	Shale	93	393
Hard slate or soapstone	18	60	Sand-rock (main flow)	63	456
Sand-rock (water not flow)	5	65	Bottom on sand rock.		

This bore is one of about thirty that have been put down in the vicinity of Miles City, Mont. The volume discharged, pressure, strata passed through, and quality of the water of this well are a fair representation of those of others in this basin, which we denominate the Miles City Basin. For additional particulars concerning this basin, see W. W. Follett's report. The receiving area for a subterranean or artesian water supply that may lie in this valley is amply large and sufficiently elevated to give the requisite pressure and volume. It is not at all unlikely that this basin extends far up and down the valley of the Yellowstone, far beyond the country yet developed. The existence of the other necessary conditions for an artesian supply are matters for the geologist to predict and the drill of the prospector to determine.

Rosenfeld Junction well.—Located in T. 166 N., R. 54 W., town of Rosenfeld Junction, State of Manitoba. Owned by Canadian Pacific Railroad. Drilled by Swan Company. Depth, 1,037 feet. Elevation above sea level, 780 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Black soil	4	4	Red shale	160	[illegible]
Blue clay	111	115	Cream-colored limestone (Galena limestone passing above Trenton)	[illegible]	[illegible]
Sand and gravel	10	125	Red shale	75	[illegible]
Bowlder clay (hardpan)	12	137	Soft sandstone (brine flow), St. Peter	[illegible]	[illegible]
Bowlders	6	143	Dark red shale	[illegible]	[illegible]
Gray shale	62	205	Reddish and green shale	[illegible]	1,[illegible]
Limestone	15	220	Bluish and gray shale	[illegible]	1,[illegible]
Red shale	5	225	Red shale	15	1,[illegible]
Gray shale	10	235	Laurentian granite	2	1,[illegible]
Limestone	30	265			
Fine gray sandstone (small flow brine)	40	305			
Chalky limestone	36	[illegible]			

Reference to this bore is made for the value of its log, which appears to have been carefully kept. The two small flows obtained were both salty; recorded as being brine. Granite was struck at 1,037 feet. Location in this bore is given by projecting the United States land surveys.

Deloraine City well.—Manitoba. Owned by city and government. Commenced in 1887. Depth, 1,800 feet. Cost, $13,000. Elevation above sea level, 1,620 feet.

Strata passed through are as follows:

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Black surface soil	3	3	Soapstone, with streaks of limestone	465	757
Clay loam, with gravel and pebbles	30	33	Blue clay, with small shells	135	892
Hardpan, with blue clay	56	89	Slate (soft), soapstone, and mud	908	1,800
Fine sand	5	94			
Shale and slate, with layers of sand	198	292			

This bore is noticed on account of its location. It is about 10 miles beyond the boundary line in Canada, and is located about 60 miles west of an axial line through the developed section of the Dakota artesian basin, as represented in map, Appendix No. 16. The sinking of this bore was first undertaken by the town of Deloraine, to obtain water for municipal purposes. The town authorities were induced to believe they would strike the artesian flow at about the same level as the nearest well in the United States, which is at Devils Lake. To do this would require a bore about 1,578 feet deep. This depth was reached and no water found. The work was stopped until the Dominion Government came to the relief of the town, and for the further purpose of making a test exploration of the rock strata. It is intended to continue to sink the bore until the water-bearing strata is reached, provided it lies within a reasonable distance. Its present depth (August 1891), is 1,800 feet, or 180 feet below sea level, or 133 feet lower than the bottom of the bore at Devils Lake. These figures indicate that the artesian stratum is either missing entirely or it lies at a greater depth in that locality than is due to its average inclination to the northward, as determined by the bores in the Dakotas. The discovery which will be made by continuing this bore a few hundred feet deeper will be of considerable importance concerning the probability of obtaining artesian water in the middle section of North Dakota, which borders on the Canadian line.

THE SOURCE OF SUPPLY OF THE DAKOTA ARTESIAN BASIN.

Geologists generally agree that the water from the deep flowing wells in the James River, or Dakota artesian basin, is found in a group of stratified rock, which they denominate as the Dakota. This rock, they claim, comes to the surface in the region of the Black Hills, in southwestern South Dakota; also along the drainage channels of the Missouri and Yellowstone rivers. It is supposed this soft and porous rock has the necessary properties to imbibe water freely and to permit it to be transmitted through it, even for long distances.

The localities where these rocks are exposed to the surface waters are from 2,500 to 6,000 feet above sea level, and the sections which are tapped by the bores in the artesian basin are from 800 feet above to 100 feet below sea level, thereby affording condition for supporting an immense hydraulic pressure, which is sufficient in some places in this basin to raise a column of water to a greater height than the surface of the country for hundreds or even a thousand miles in any direction, except to the west. Therefore, it is almost certain that the water supply must come from that direction. It is reported by those who have had occasion to observe the flow of water at a low stage in the upper Missouri River that between Great Falls and Fort Benton, Mont., there

TABULATION OF ARTESIAN WELL DATA.

[From ninety-seventh meridian to foothills of Rocky Mountains.]

No. of well.	Name of well.	Town.	County.	State.	Owner.	Informant.	By whom drilled.	When well was completed.	Depth (in feet) at which different flows were struck.	Total depth of well.	Surface of well.
										Feet.	Feet.
1	Plankinton	Plankinton	Aurora	South Dakota	Plankinton	Gray Bros., Milwaukee, Wis	Gray Bros., Milwaukee, Wis	Fall, 1890	First, 540; second, 740	880	1,321
2	White Lake	White Lake	do	do	White Lake		Swan Bros., Andover, S. Dak	Fall, 1887	First, 790; second, 850	863	1,350
3	Collins	Cavour	Beadle	do	Township		J. C. Weston, Huron, S. Dak				1,321
4	Hitchcock	Hitchcock	do	do	Hitchcock	C. W. A. Reynolds, Hitchcock	Gray Bros., Milwaukee, Wis	August, 1885	First, 926; second, 953	958	1,330
5	City	Huron	do	do	Water Company		Swan Bros., Andover, S. Dak	In 1886	First, 712; second, 772	906	1,251
6	Day-Harrison	do	do	do	F. T. Day	C. M. Harrison	Roberts	May 1, 1890	First, 770; second, 835	947	1,268
7	Huron Mill	do	do	do	Huron	F. Holton	Howard Holton Bros	Sept. 1, 1889	First, 734; second, 800		1,270
8	Richards	do	do	do	American Investment Co	R. O. Richards, Huron, S. Dak	Swan Bros., Andover, S. Dak	Nov. 15, 1889	First, 789; second, 789	917	1,280
9	Risdon	do	do	do	A. H. Risdon	J. C. Weston, Huron	J. C. Weston, Huron, S. Dak	March, 1891	Fourth, 600; fifth, 640; sixth, 690; seventh, 700; eighth, 802	[illegible]	1,280
10	Wolsey	Wolsey	do	do	Wolsey		Swan Bros., Andover, S. Dak	Sept., 1890	First, 490; second, 808; third, 858	960	1,346
11	Scotland	Scotland	Bonhomme	do	Scotland		Carr & Ritchie, Yankton, S. Dak	In 1887	First, 512	587	1,338
12	Springfield	Springfield	do	do	Bonesteel & Turner	J. L. Turner, Springfield	Gray Bros., Milwaukee, Wis	Spring, 1891	First, 440; second, 530	592	1,375
13	Tyndall	Tyndall	do	do	Tyndall	Vincent Kalemar, mayor	Carr & Ritchie, Yankton, S. Dak	In 1888	First, 700	735	1,410
14	Lason	do	do	do	H. P. Lason	H. P. Lason, Tyndall	H. P. Lason, Tyndall	April, 1891	First, 832; fourth, 1,040	1,075	*1,500
15	Mill	do	do	do		Vincent Kalemar, Tyndall		Sept. 3, 1891	First, 700	752	1,410
16	Milwaukee R. R	Aberdeen	Brown	do	Chicago, Milwaukee & St. Paul R. R		Swan Bros	March, 1882	First, 880; second, 890; third, 925; fourth, 940	965	1,300
17	City well No. 1	do	do	do	Aberdeen	Gray Bros., Milwaukee, Wis	Gray Bros., Milwaukee, Wis	In 1883	First, 879; second, 905	918	1,300
18	City well No. 2	do	do	do	do	do	do		First, 895; second, 946	1,004	1,300
19	City well No. 3	do	do	do	do	Robt. Moody, mayor	Am. Well Works (Wheeler)		First, 910; second, 921; third, 1,016	1,066	1,300
20	Beard	do	do	do	H. C. Beard	H. C. Beard, Aberdeen	Gray Bros., Milwaukee, Wis	October, 1890	First, 940; second, 1,000	1,050	1,303
21	Columbia	Columbia	do	do	Columbia	G. M. Lyon, mayor	Swan Bros., Andover, S. Dak	In 1885	First, 721; second, 801; third, 862; fourth, 892; fifth, 927	964	1,315
22	Flanders	do	do	do	Chas. Flanders	Chas. Flanders, Columbia	Chas. Flanders, Columbia		First, 681; second, 724; third, 782; fourth, 912	965	
23	Heman	do	do	do	H. L. Heman	H. L. Hemans, Columbia	H. L. Hemans, Columbia		First, 560		*1,250
24	Frederick	Frederick	do	do	Frederick		Swanson, Minneapolis, Minn	May 15, 1890	First, 985	1,130	1,333
25	Krouschnabel	do	do	do	Caspar Krouschnabel	Caspar Krouschnabel, Frederick	Caspar Krouschnabel, Frederick				1,375
26	Abbott	do	do	do	Abbott & Morgan	Wallace Abbots, Frederick	Abbott & Morgan				*1,400
27	Groton No. 2	Groton	do	do	Groton	J. A. Bowler, mayor	Swan Bros., Andover, S. Dak	August, 1889		922	1,304
28	F. D. Adams	do	do	do	F. D. Adams	David Harris	Jas. Anderson	May 4, 1891	First, 906; second, 917	977	1,305
29	Burnham	do	do	do	W. A. Burnham	W. A. Burnham, Groton	W. A. Burnham, Groton	Jan. 27, 1891	First, 725; second, 840	842	1,305
30	Groton No. 1	do	do	do	Groton	Gray Bros., Milwaukee, Wis	Gray Bros., Milwaukee, Wis		First, 925	960	1,304
31	Kimball	Kimball	Brule	do	Kimball	Louie Richards, Kimball	do	In 1887		1,068	1,781
32	City well	Chamberlain	do	do	City	Scott Hayes, city engineer	Page Guthrie	May, 1891	First, 716; second, 750; third, 780; fourth, 785	785	1,547
33	Hammer	Castalia	Charles Mix	do	A. A. Hammer	Geo. H. Waters, Armour, Douglas Co		do		966	1,610
34	Clark	Clark	Clark	do	Clark		Siers Bros., De Smet				
35	Mitchell	Mitchell	Davison	do	Mitchell	A. M. Bowdle, mayor	Mars & Miller, Chicago, Ill	Jan. 9, 1886	First, 285; second, 530	548	1,316
36		do	do	do	Investment Co	L. Q. Hardesty, Mitchell, S. Dak	Thos. Ball, Mitchell, S. Dak	April, 1891		507	1,344
37	Schlund	Mt. Vernon	do	do	W. H. Schlund	A. D. Dougan, Plankinton, S. Dak	W. H. Schlund	October, 1890		838	*1,375
38	Andover	Andover	Day	do	Chicago, Milwaukee & St. Paul R. R		Swan Bros, Andover, S. Dak	In 1882	Main, 1,070	1,075	1,505
39	Armour	Armour	Douglas	do	Armour	A. E. Swan	do	Jan. 7, 1891	Main, 696	757	1,514
40	Ipswich	Ipswich	Edmunds	do	Ipswich	J. J. Skahen	Gray Bros., Milwaukee, Wis	Fall, 1884	First, 1,000; second, 1,230	1,290	1,551
41	Orient	Orient	Faulk	do	Faulk County	R. O. Richards	Swan Bros., Andover, S. Dak	June, 1891	First, 394; second, 1,050; third, 1,070; fourth, 1,165	1,215	1,565
42	Miller	Miller	Hand	do	Miller	Gray Bros., Milwaukee, Wis	Gray Bros., Milwaukee, Wis	In 1886	First, 1,116	1,145	1,590
43	Harrold	Harrold	Hughes	do	Harrold		Swan Bros., Andover, S. Dak	In 1888	First, 1,060; fifth, 1,435	1,453	1,600
44	Highmore	Highmore	Hyde	do	Highmore	Gray Bros., Milwaukee, Wis	Gray Bros., Milwaukee, Wis	March, 1887	First, 1,537	1,552	1,690
45	Iroquois	Iroquois	Kingsbury	do	Iroquois	C. Fred. Zimmerman	do	October, 1890	First, 400; second, 600; third, 850	1,100	1,482
46	Madison	Madison	Lake	do	Madison	Chas. R. Kennedy, mayor	City of Madison		First, 600		1,660
47	Britton	Britton	Marshall	do	Britton	C. A. Cooper	Swan Bros., Andover, S. Dak	Mar. 25, 1889	First, 880; second, 976	1,004	1,352
48	Bridgewater	Bridgewater	McCook	do	Bridgewater	Col. C. H. Chandler	Col. C. H. Chandler, Bridgewater	June 2, 1891	First, 224	229	1,418
49	Salem	Salem	do	do	Salem		Swan Bros	Fall, 1887	First, 215	247	1,517
50	McCurdy	Letcher	Sanborn	do	Frank McCurdy	Frank McCurdy	C. O. Hutchins, Woonsocket	Aug. 13, 1890	First, 505; second, 514; third, 552; fourth, 563	578	1,310
51	Letcher	do	do	do	Letcher	H. E. Mayhew	City of Letcher	July, 1891	First, 300; second, 400; third, 570	577	1,300
52	Woonsocket	Woonsocket	do	do	Woonsocket	Gray Bros., Milwaukee, Wis	Gray Bros., Milwaukee, Wis	In 1890	First, 684	725	1,306
53	Mill well	do	do	do	Northey & Duncan		Robbins & Vowe	do	First, 645; second, 690; third, 697	775	1,316
54	Hines	do	do	do	Charles E. Hines	Chas. E. Hines	Chas. E. Hines	March, 1891		742	1,348
55	Ashton	Ashton	Spink	do	Chicago, Milwaukee & St. Paul R. R		Swan Bros	In 1883	First, 650; second, 795; third, 905	925	1,296
56	Doland	Doland	do	do	Doland		do	In 1889	First, 500; second, 880	807	1,350
57	Lebrie	do	do	do	Joseph Lebrie	Jos. Lebrie	Jos. Lebrie				
58	Frankfort	Frankfort	do	do	Frankfort		Swan Bros	About 1888	First, 803; second, 865; third, 945; fourth, 1,000	1,008	1,296
59	Mellette	Mellette	do	do	Mellette	P. S. Stacey	W. E. Swan Co., Andover, S. Dak	Dec. 24, 1889		920	1,304
60	Brum	do	do	do	E. Brum	E. Brum	E. Brum, Mellette	Dec., 1890	First, 500; third, 880; main, 925	958	1,380
61	Gallup	do	do	do	Gallup		Gauge				
62	Baker	do	do	do	J. W. Baker	J. W. Baker	Swan Bros	Mar. 1, 1891	First, 400; third, 871	920	1,275
63	Day	do	do	do	J. P. Day	J. P. Day	do	May 1, 1891	First, 700; third, 915	908	1,285
64	Bird	do	do	do	Rowbothan, Bird & Moore	P. J. Stacey	Swan Co	Sept. 1, 1891	First, 902	930	1,280
65	do	do	do	do	do	Wm. Rowbothan	Swan Bros	do		910	1,290
66	Redfield	Redfield	do	do	Redfield	Mayor A. Komenerer	Gray Bros., Milwaukee, Wis	In 1886	First, 750; third, 944	964	1,300
67	J. F. Hall	do	do	do	J. F. Hall	P. J. Stacey	W. E. Swan Co	October 24	First, 890; second, 927	987	1,302
68	Fridley	Turton	do	do	John Fridley	John Fridley					
69	Fort Sully	Fort Sully	Sully	do	United States Government		Aurora Well Co			970	
70	Fort Randall	Fort Randall	Todd	do	do	Lieut. M. McFarland		Jan. 25, 1886	First, 460; second, 520; third, 610	610	1,[illegible]
71	Mill well	Yankton	Yankton	do	Miner & Walker	Miner & Walker	Carr & Ritchie	In 1883		505	1,190
72	Wilcox	do	do	do	E. P. Wilcox	E. P. Wilcox		In 1890	First, 432	455	1,168
73	Cement works	do	do	do	W. Portland Cement Co	Robt. Yates, mayor	Gray Bros., Milwaukee, Wis	Fall, 1890	First, 375; second, 390; third, 405; fourth, 435; fifth, 450	500	1,200
74	Asylum	do	do	do	State South Dakota	Dr. Meade, superintendent insane asylum		In 1887	First, 600	672	1,[illegible]
75	City well	do	do	do	Yankton	Water commissioner	Carr & Ritchie	Spring, 1882	First, 610	615	1,[illegible]
76	Court	Buffalo	Cass	North Dakota	H. E. Sargent	H. D. Court, Buffalo, N. Dak	George Frazer	Summer, 1889		600	1,190
77	Staples	do	do	do	Staples	W. A. Metzger, Absaraka, N. Dak		do		514	1,170
78	Tower City	Tower City	do	do	Northern Pacific R. R. Co	Chas. Petsold, Colgate, N. Dak	Chas. Petsold, Colgate, N. Dak	June, 1882	First, 716	716	1,168
79	Bismarck	Bismarck	Burleigh	do	Bismarck	P. J. Stacey, Aberdeen, S. Dak	Swan Bros., Andover, S. Dak	In 1883		1,315	1,738
80	Ellendale	Ellendale	Dickey	do	Ellendale	Gray Bros., Milwaukee, Wis	Gray Bros., Milwaukee, Wis	April 6, 1886		1,087	1,468
81	Jones	do	do	do	W. H. Jones	A. T. Hayman, Ellendale, N. Dak	A. T. Hayman, Ellendale				
82	Oakes	Oakes	do	do	Oakes		Swan Bros	March, 1890	Third, 790; fourth, 845; fifth, 870; main, 937	972	1,319
83	Mandan	Mandan	Morton	do	Mandan	D. M. Bougard, Mandan, N. Dak	Gray Bros., Milwaukee, Wis		First, 120; second, 410	1,580	1,645
84	Hamilton	Hamilton	Pembina	do	Hamilton Artesian Well Co	H. N. Jay, Hamilton, N. Dak	W. B. Clements, Cavalier, N. Dak	August, 1889	First, 300; second, 1,241	1,556	824
85	Devils Lake	Devils Lake	Ramsey	do	Devils Lake	City auditor	Swan Bros., Andover, S. Dak	July, 1889		1,520	1,473
86	Jamestown	Jamestown	Stutsman	do	Jamestown	Gray Bros., Milwaukee, Wis	Gray Bros., Milwaukee, Wis	April 4, 1887	First, 1,385; second, 1,458	1,476	1,391
87	Asylum	do	do	do	State North Dakota		do	November, 1890		1,524	1,470
88	Grafton	Grafton	Walsh	do	Grafton	A. E. Swan, Andover, S. Dak	Swan Bros., Andover, S. Dak	June 20, 1885	First, 195; second, 270; third, 390	912	825
89	Moorhead	Moorhead	Clay	Minnesota	Moorhead	Andrew Holes, Moorhead, Minn	Gray Bros., Jamestown and city of Moorhead.	Oct. 21, 1889		1,901	901
90	Chinook	Chinook	Choteau	Montana	C. Artesian Co	Thomas O'Hanlon	Hired employés		First, 112; second, 220; third, 540; fourth, 620	956	2,404
91	Beck	Miles City	Custer	do	O. C. Beck	O. C. Beck	O. C. Beck, Miles City, Montana	June, 1886	First, 250; second, 300; third, 393	456	2,363
92	Rosenfeld Junction	Rosenfeld Junction		Manitoba	Canadian Pacific R. R. Co		Swan Co		First, 875	1,087	780
93	Deloraine City			do	City and Government	Mr. Stephens				1,800	1,620

* Estimated. † Very weak; just comes to surface. ‡ Large; fills 8-inch pipe. § Can not now be measured. ‖ 1,400 in 1890. ** In 1890.

F ARTESIAN WELL DATA.

dian to foothills of Rocky Mountains.]

	When well was completed.	Depth (in feet) at which different flows were struck.	Total depth of well.	Elevation above sea.			Flow (in gallons) per minute.	Pressure (in pounds) per square inch when well is closed.	Temperature of well.	Cost of well.
				Surface of well.	Bottom of well.	Different flows of water.				
			Feet.	Feet.	Feet.	Feet.			°	
	Fall, 1890	First, 540; second, 740	830	1,521	691	First vein, 981; main vein, 781	225	91	63	$3,200
	Fall, 1887	First, 790; second, 850	863	1,650	787	First vein, 860; main vein, 800	150	35	64	2,800
				1,831						
	August, 1885	First, 926; second, 953	958	1,339	381	First vein, 413; main vein, 386	1,240	154	70	4,400
	In 1886	First, 712; second, 772	906	1,251	345	First vein, 539; main vein, 479	1,668	120		4,000
	May 1, 1890	First, 776; second, 836	847	1,306	459	First vein, 530; main vein, 470	496	120		1,653
	Sept. 1, 1890	First, 724; second, 790		1,270		First vein, 546; main vein, 480	700	108		2,000
	Nov. 15, 1890	First, 780; second, [illegible]	917	[illegible]	[illegible]	First vein, 551; main vein, 501				2,000
	March, 1891	Fourth, 600; fifth, 640; sixth, 690; seventh, 700; eighth, 902	900	1,290	390	Fourth vein, 690; fifth, 650; sixth, 600; seventh, 590; eighth, 388; main, 390.	2,250	185		
	Sept., 1890	First, 490; second, 808; third, 858	930	1,348	418	First vein, 858; second, 540; main, 490	330	137	76	2,500
	In 1887	First, 512	587	1,338	751	First vein, 826	9			2,050
	Spring, 1891	First, 440; second, 530	592	1,275	683	First vein, 835; second, 745	3,290	86	65	2,460
	In 1888	First, 700	735	1,410	675	First vein, 710	580	35	62	2,544
	April, 1891	First, 822; fourth, 1,040	1,075	*1,560	485	First vein, 738; second, 520	(†)			1,650
	Sept. 3, 1891	First, 700	752	1,410	658	First vein, 710	(‡)	40		
	March, 1883	First, 880; second, 890; third, 925; fourth, 940	955	1,300	345	First vein, 420; second, 410; third, 375; main, 360	(§)	100		4,300
	In 1882	First, 879; second, 905	918	1,300	382	First vein, 421; main, 395	330	40	66	4,000
		First, 595; second, 946	1,004	1,300	296	First vein, 705; main, 354	825	62	66	4,000
		First, 910; second, 921; third, 1,016	1,066	1,300	234	First vein, 390; second, 379; main, 284				
	October, 1890	First, 940; second, 1,000	1,050	1,303	253	First vein, 363; main, 303	1,060	138		3,050
	In 1885	First, 721; second, 801; third, 862; fourth, 892; fifth, 927	964	1,315	351	First vein, 594; second, 514; third, 453; fourth, 423; main, 388	‖ 940	160	63	3,200
		First, 681; second, 724; third, 782; fourth, 912	965					135		5,000
		First, 560		*1,350		First vein, 790				2,800
	May 15, 1890	First, 985	1,139	1,383	244	First vein, 398; main, 338	135	70	69	3,600
				1,375						
				*1,495						
	August, 1889		922	1,394			** 830	135		
	May 4, 1891	First, 906; second, 917	977	1,305	382	Main, 415	105	80	63	1,500
	Jan. 27, 1891	First, 725; second, 840	842	1,305	328	First vein, 390; main, 388	150	137	63	2,500
		First, 925	966	1,304	363	First vein, 580; main, 465				
	In 1887		1,068	1,781	344	Main, 379	185	20	68	4,500
	May, 1891	First, 716; second, 750; third, 780; fourth, 785	785	1,547	713	Main, 713	529.62	122	74	2,500
	do		966	1,610	762	First vein, 831; second, 797; third, 767; main, 762	30	50		1,500
					644					
	Jan. 9, 1886	First, 285; second, 530	548	1,316				7		3,150
	April, 1891		507	1,344	768	First vein, 1,031; main, 786	40		56	
	October, 1890		338	*1,275	937	First vein, 924	40			
	In 1882	Main, 1,070	1,075	1,505	1,637			65		
	Jan. 7, 1891	Main, 696	757	1,514	757	First vein, 818	1,500	55	60	3,000
	Fall, 1884	First, 1,000; second, 1,230	1,230	1,531	301	First vein, 531; main, 301	40	106	71	5,200
	June, 1891	First, 394; second, 1,050; third, 1,070; fourth, 1,165	1,215	1,565	350	First vein, 1,171; second, 515; third, 495; main, 400	950	130	75	4,900
	In 1886	First, 1,116	1,145	1,586	441	Main, 470	400	100	73	4,010
	In 1888	First, 1,000; fifth, 1,435	1,453	1,800	347	First vein, 800; fifth, 365	85	27	94	
	March, 1887	First, 1,537	1,552	1,900	348	First vein, 470; main, 363	9	12½	72	7,200
	October, 1890	First, 400; second, 600; third, 850	1,100	1,403	303	First vein, 1,003; second, 803; main, 553	100	67	73	3,400
		First, 600		1,600						
	Mar. 25, 1889	First, 880; second, 976	1,004	1,352	348	First vein, 472; main, 376	**600	115	64	3,614
	June 2, 1891	First, 224	229	1,413	1,184	First vein, 1,189				516
	Fall, 1887	First, 215	247	1,517	1,270	Main, 1,302				
	Aug. 13, 1890	First, 505; second, 514; third, 552; fourth, 568	578	1,310	722	First vein, 795; second, 786; third, 748; fourth, 783	70			700
	July, 1891	First, 300; second, 400; third, 570	577	1,300	723	First vein, 1,000; second, 900; main, 730	80	90	58	1,800
	In 1890	First, 684	725	1,308	583	Main, 624	1,150	130	65	3,820
	do	First, 645; second, 690; third, 697	775	1,316	541	First vein, 671; second, 626; main, 619		125	65	4,500
	March, 1891		749	1,348	599	Main, 659	425	131	65	900
	In 1883	First, 650; second, 795; third, 905	925	1,296	371	First vein, 646; second, 501; main, 391	100	60		4,000
	In 1889	First, 500; second, 880	897	1,350	453	First vein, 850; main, 470	370	122	64	
	About 1888	First, 803; second, 865; third, 945; fourth, 1,000	1,008	1,296	288	First vein, 493, second, 431; third, 351; fourth, 296				4,032
	Dec. 24, 1889		930	1,304	374	Main, 410	**1,215	106	65	3,100
	Dec., 1890	First, 500; third, 880; main, 925	958	1,280	322	First vein, 780; second, 400; main, 355	60	141	65	2,100
	Mar. 1, 1891	First, 400; third, 871	920	1,275	355	First vein, 875; main, 404			65	2,700
	May 1, 1891	First, 700; third, 915	993	1,285	292	First vein, 585; main, 370	1,300	135	65	3,070
	Sept. 1, 1891	First, 902	930	1,280	350	Main, 378	670	153	65½	2,400
	do		910	1,290			670	153	65½	
	In 1886	First, 750; third, 944	964	1,300	336	First vein, 550; main, 356	**1,260	177	64	2,900
	October 24	First, 890; second, 927	987	1,302	315	First vein, 412; main, 375				2,500
			979							
	Jan. 25, 1886	First, 460; second, 520; third, 610	610	1,245	635	First vein, 785; main, 725; third, 635	600		80	2,572
	In 1883		505	1,010	505		1,450	48	63	2,500
	In 1890	First, 432	455	1,168	713	Main, 736	330	65	60	450
	Fall, 1890	First, 375; second, 390; third, 405; fourth, 435; fifth, 450	500	1,200	700	First vein, 825; second, 810; third, 795; fourth, 765; main, 725	1,300	50	64½	2,500
	In 1887	First, 600	672	1,285	613	Main, 685	165	10	64	2,500
	Spring, 1882	First, 610	615	1,259	644	Main, 649	880	18	63	3,000
	Summer, 1889		600	1,190	590	Main vein, 630	12	45	63	3,200
	do		514	1,170	656	Main vein, 670	25	50	51½	1,500
	June, 1882	First, 716	716	1,168	452	Main vein, 452	20–25	53	57	2,200
	In 1883		1,315	1,756	441					
	April 6, 1886		1,087	1,463	376	Main vein, 421	**700	115	69	4,440
	March, 1890	Third, 790; fourth, 845; fifth, 870; main, 937	972	1,319	347	Main vein, 386	817	125	63	
		First, 120; second, 410	1,590	1,645	55	First vein, 1,505; second, 1,235		30		
	August, 1889	First, 300; second, 1,241	1,560	824	–736	First vein, 524; second, –417	26	27	41½	10,150
	July, 1889		1,520	1,473	–47	Main vein, 42 to –40	82	20	62	9,000
	April 4, 1887	First, 1,385; second, 1,458	1,476	1,391	–85	First vein, 6; main vein, –67	460	97	76	6,700
	November, 1890		1,524	1,470	–54	First vein, –9; second vein, –35	4	70		7,000
	June 20, 1885	First, 195; second, 270; third, 390	912	825	–87	First vein, 630; second vein, 555; third, 435	600	12	46	3,500
Moor-	Oct. 21, 1889		1,901	901	–1,000	First vein, 781; second vein, 101; third, –40				10,000
		First, 112; second, 220; third, 540; fourth, 620	956	2,404	1,448	First vein, 2,292; second vein, 2,184; third, 1,864; fourth, 1,784			40	4,400
	June, 1886	First, 250; second, 300; third, 393	456	2,413	1,957	First vein, 2,163; second vein, 2,053; third, 1,960	5	7	57	575
		First, 875	1,037	780	–257	First vein, –95				
			1,800	1,620	–180					12,000

8-inch pipe. § Can not now be measured. ‖ 1,400 in 1890. ** In 1890.

is a perceptible difference in the volume of water, there being less at Fort Benton than at Great Falls, some 40 miles up the river.

This reported decrease of volume between these places has suggested the idea that possibly a portion of the supply of water in the artesian basin under consideration may come from this point.

A reconnoissance of this locality was made in August, when it was found to be practicable to detect any considerable difference in the volume of the river by a series of gaugings at several points between Great Falls and Fort Benton. As the river was gradually falling it was decided to defer making these measurements until the close of the field season, or when the volume of the river would be at or near its minimum, for having as little water as possible to deal with would tend to reduce the percentage of error in the measurements.

Before closing the fall work a few days were spent in making measurements of the river and other investigations of this supposed source of the water supply. It is to be regretted that this part of the investigation could not have been made jointly by the geologist and the engineer, as this is an interesting and important field of inquiry. As the absence of the geologist could not be avoided, we were compelled to take up some lines of investigation that do not properly belong to engineering questions, or else to simply collect certain engineering data which of itself would not be sufficient to establish with any degree of certainty that this outcropping is one of the points where the artesian supply enters the water-bearing strata. The geological data required has, however, been fortified by a valuable paper annexed to this division.

The Missouri River* first comes in contact with the Dakota sandrock at the city of Great Falls. From this point it begins to cut down into the rock, forming a cañon with almost vertical walls which are composed of parallel strata of rock varying from a few inches to 15 feet in thickness. These strata are generally sandstone of different degrees of hardness, color, etc. Some of them contain considerable lime and clay. Between these strata are beds of shale, soapstone, lignite, conglomerate, with water-worn pebbles and cobblestones embedded in the sand. These beds range from 2 feet to 4 feet thick. The whole formation seems to have in very many ways the same characteristics of the water-bearing rock in the Dakota artesian basin, as is revealed by the logs of the hundreds of bores of which we have record.

At the city of Great Falls there is apparently a ledge of rock running across the Missouri River Valley which forces the river to near the surface of the country. On the upper side or crest of the rock is what is locally called the "bay," which is a little widening and deepening of the channel, the water of the river being backed up for 2 or 3 miles. The river passing over the crest of this outcropping resembles the spillway of a rock dam about 1,500 feet long.

The top of the rock at this point is quite hard, over which the flow of the river for ages has made but little impression.

Immediately after passing over the crest, the river falls rapidly and begins to cut its way into the somewhat softer rock for some 3 miles from the crest, then it plunges down 30 or 40 feet, forming what is known as the Black Eagle Falls. At the bottom of this cascade is a hard stratified rock resembling quartzite, which has prevented the river cutting deeper at this point.

Then for 2½ miles there is another stretch of rapids where the river cuts still deeper into the rock, then it falls perpendicularly about 12 feet on a hard stratum of rock about 5 feet in thickness. About one-third of a mile below it again falls perpendicularly about 45 feet, forming the Rainbow Falls. Below these falls is another short stretch of rapids of one-half mile. Then it makes another drop of 20 feet, then comes another stretch of rapids 4 miles long, when the river makes its last and perpendicular plunge of 90 feet. These falls are called the Great Falls of the Missouri River.

---

* See Appendices 22 and 23.

From this point to the mouth of Belt River, some 6 miles, the average slope of the river is greatly decreased, it being about 20 feet per mile. A short distance below the Great Falls there is a narrow and very deep channel in the river bed, through which nearly the whole volume of the river flows during a medium stage of water.

This deep channel is from 75 to 100 feet in width, its depth is unknown, but it is so deep that a flow through it of 6,000 to 8,000 cubic feet per second produces a current that is hardly perceptible. Probably this deep channel was cut out of soft rock by the action of the water at the time the Great Falls were at this point, as they undoubtedly were at one time, as there are evidences that these falls have been gradually receding.

From the upper end of the first rapids to the bottom of the Great Falls the average of the slope of the river bed exceeds the dip of the rock by some 200 or 300 feet. From the foot of the Great Falls to the mouth of Highwood Creek the slope of the river is considerably less than the dip of the rock, so that in a short distance eastward from the latter place the top of the rock passes under the river channel and disappears.

From this point the river channel is cut into the shales which overlie the sand rock, and the slope of the river bed assumes its normal grade, which is only about 4 feet per mile. The point where the Dakota rock passes under the river marks the head of navigation on the Missouri River, and from here the clear water of the river becomes colored by the erosion of the shales, which is the beginning of the "Big Muddy."

The relation of the dip of the rock strata to the surface of the river bed is shown by the sketch marked as "Appendice 23."

We will call that portion of the river above the Great Falls the upper section and that below the lower section.

The river in passing down the channel of the upper section forms a cañon which grows deeper as long as it continues cutting through the rock which it has done until it reaches the foot of the Great Falls. From here the relation between the inclination of the strata and the river bed is reversed. The grade of the river below the Great Falls is very much reduced, it being as much less than the dip of rock as the inclination was greater in the section above, and from this point instead of the river cutting down through the strata; from now on the process has been reversed and the river from here on is passing over the edges of all the strata it cut through in the upper section, which now affords an opportunity to imbibe the water from the river. Whether the rocks do, or do not, take in water from the river is the question to be solved, and this was accomplished by accurate measurements of the volume of the river above and below the lower section.

The upper measurement was made about 8 miles above the Great Falls; the lower one at Fort Benton, about 30 miles below. The only surface water that enters the river between these places (except it may be a very small amount from a few springs) was from the Belt and Highwood Creeks, which amounted to 85 cubic feet per second.

Near the place where the upper gaugings were made is a group of springs, one large one being in the channel of the river, the other on the right bank just a little above the surface of the water. It seemed desirable to ascertain the flow from these springs, and to do so required a gauging of the river above and below. The difference in the flow at these points, of course, would be the discharge of the springs, therefore two gaugings were made of the upper section. The gaugings were made by carefully measuring a cross-section of the stream by taking depths and distances in a skiff. The velocity of the current was obtained by an electric current meter. The points at which the velocities of the measurements were taken were located by angular measurement, taken by a sextant in the boat. These stations were from 25 to 75 feet apart and between them several measurements of the depth were made. From these data the following results were obtained:

The volume of the river above the springs was 3,885 cubic feet per second. The volume of the river below the springs was 4,523 cubic feet per second, the difference being 638 cubic feet per second, or the volume discharged by the springs. The volume of the river at Fort Benton was 3,774 cubic feet per second, being 749 cubic feet per second less than the volume of the flow below the Giant Springs. To this must be added 85 cubic feet per second, the amount that the river is reënforced by Belt and Highwood creeks. Therefore we have 834 cubic feet per second of water that is apparently lost somewhere between Fort Benton and the foot of the Great Falls.

The fact that a certain amount of water disappears is now demonstrated by actual measurement. The possibility of this lost water being held within and carried down the incline of this rock strata to the James River artesian basin, which is some 600 miles distant, remains to be determined before the statement can be positively made that this is one of the sources of the artesian supply found in the Dakotas. If there is a continuity of the rock formation that we have been considering through this 600 miles and its structure is the same throughout its entire length, as we find at Great Falls in the basin where the artesian flow is found, I think we are justified in the statement that it is possible for this water to travel this long distance underground.

The immense volume of water flowing from the Giant Springs is nothing more or less than an artesian flow. The water comes up through a rock which appears to have been uplifted by a tremendous pressure from below. The strata for 50 to 75 feet around are broken up, resembling a condition that would exist if a heavy charge of giant powder had been exploded in a drill hole 20 or 30 feet deep at this place. The surrounding rock is all in place, but this deep hole is filled with broken rock. The water from these springs must come from the subterranean channels in this Dakota rock. There is a close resemblance of the quality of the water to that of the artesian well water in South Dakota, especially in the southern portion of the basin.

The following is an analysis made by Prof. James A. Dodge, of the University of Wisconsin:

	Grains per gallon.
Sulphate of lime (gypsum)	14.04
Carbonate of lime	4.38
Carbonate of magnesia	4.98
Chloride of sodium (common salt)	.56
Salts of potassium	Traces.
Salts of lithium	Traces.
Borates	Slight traces.
	23.96

Hardness, 23 degrees.

Organic analysis.

Free ammonia	.01 part per 1,000,000
Albuminoid ammonia	None.
Nitrates and nitrites	None.

The temperature of the water of these springs is 51¼ degrees, and it is said there is no change of temperature between winter and summer.

It is the opinion of people who are acquainted with this part of the country that the water from these springs comes from the Belt Mountains some 15 or 20 miles to the southeast. It is reported also that the water in the Belt and some other creeks all sinks during a low stage of water into the rockbound channels of these creeks. The rocks skirting the northerly side of the mountains are said to be the same as found at Great Falls and under this sandstone rock lies a thick bed of limestone. This is the same arrangement of strata as has been found in some of the deep wells in the Dakota basin. There are other opinions that the water from these springs comes from the Missouri River some two or three miles to the southwest, as the river in that direction is sufficiently above the springs to force the water to the surface. The difference in the quality of the spring and river water and the temperature of the two does not support this theory. It is hardly to be supposed that so large a volume of water as these springs discharge (over 413,000,00 gallons per diem) would in so short a distance as two or three miles produce such differences in quality and temperature as occur between the river and the spring, as the water in the river is quite soft and comparatively free from magnesia and gypsum and the temperature of the water has an annual range of from 40 to 50 degrees.

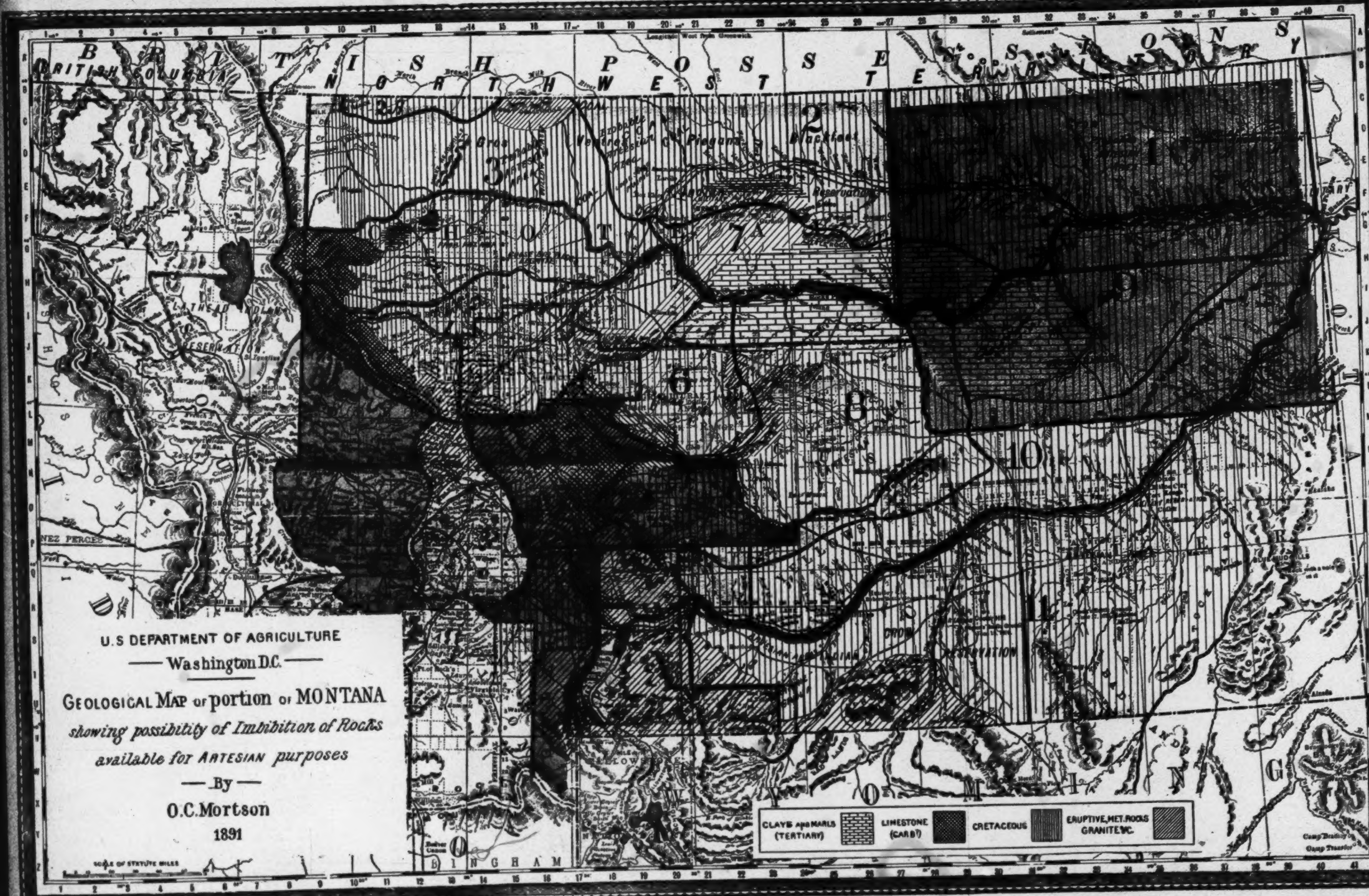
REPORT ON THE GEOLOGICAL CHARACTER OF CERTAIN SECTIONS OF THE STATE OF MONTANA, SHOWING THE POSSIBILITY OF IMBIBITION OF WATER WHICH WOULD BE AVAILABLE FOR ARTESIAN PURPOSES.

[BY O. C. MORTSON.]

Since 1867 I have been constantly exploring the region in Montana between the Rocky Mountains and the Dakota boundary, both geologically and topographically. My mass of notes made is therefore very large, and if taken *in extenso* would necessarily be too bulky for this report. I shall therefore briefly refer to each locality separately, giving its general characteristics, make deductions, and indicate from my line of view the probable artesian centers.

SECTION No. 1.—*Poplar and Muddy creeks.*

The watershed of this section has its commencement in the Wood Mountains across the Canada line. The principal streams are the Big Muddy Creek and Poplar River. The general direction of the streams is south-southeast. They both carry considerable water prior to entering Montana. The Big Muddy is, however, dry at its mouth most of the year; the Poplar River, on the contrary, always carries considerable water, and in spring is liable to overflows. In Montana the whole of this section pertains to the lignite formation, the dip of strata being, I should judge, slightly east of south. In places, however, on the Missouri, the strata have been so disturbed by fires burning the lignite veins that it is hard to judge. The center of the section is comparatively flat, and at points marked A on map forms sandy depressed plains. Generally speaking, the surface soil is an adobe, the bluffs north of the Missouri Valley carrying considerable alkali in various places. The general character of the strata, however, is lignite of either the close of the Cretaceous period or beginning of the Tertiary period, and is identical with those of northwestern Dakota. I would consider points A A as probable artesian centers.



U.S DEPARTMENT OF AGRICULTURE

— Washington D.C. —

GEOLOGICAL MAP of portion of MONTANA

showing possibility of Imbibition of Rocks

available for ARTESIAN purposes

— By —

O.C. Mortson

1891

CLAYS and MARLS (TERTIARY) ▤
LIMESTONE (CARB?) ▩
CRETACEOUS ▥
ERUPTIVE, MET. ROCKS GRANITE &C. ▨
BRITISH POSSESSIONS
NORTH WEST TERRITORY
BRITISH COLUMBIA
Longitude West from Greenwich
IDAHO
NEZ PERCE
FLATHEAD INDIAN RESERVATION
Piegans
Blackfeet
Reservation
CROW RESERVATION
WYOMING
DAKOTA
BINGHAM
SCALE OF STATUTE MILES
1
2
2a
3
6
7A
8
9
10
11

SECTION No. 2.—*The Milk River Valley.*

This section may properly be divided into two parts, as a portion of the Milk River Valley lies, in Canadian territory. Taking the western part of this section the following remarks are applicable. It would be an easy matter to divert the waters of St. Marys River into Milk River for irrigation purposes, but the Canadian settlers would derive the benefits therefrom first and before the American settlers living east of 111° west longitude. In this western part of the section the strata for the most part are soft white and gray sandstones, apparently of either Upper Cretaceous or Lower Tertiary. It consists of a very high ridge separating the waters of Milk and Marias rivers. The dip of strata, except on the immediate foothills of the Sweet Grass hills, is northeast.

The Sweet Grass hills are about 30 miles in length and are composed of various eruptive and metamorphic rocks and slates. The range consists of the east and west buttes, with small isolated peaks between, the northern slope being the most precipitous.

Near the 111th degree west longitude, Milk River again enters Montana, and from there on that portion of this section north of Milk River passes through a lignite formation similar to section 1 and having a slight dip to the east. Borings have been made at Chinook, but I have not yet heard the result. Frenchmans Creek, Cottonwood Creek, and east and west forks of Milk River rise quite a distance beyond the British boundary, draining the west side of the Wood Mountains and the south side of the Cypress Hills, and consequently in that region have a larger flow of water there than they have in Montana. Milk River Valley itself is wide and flat, having a considerable depth of alluvial soil. Lignite coal is found as marked on the map.

On the south side of Milk River the same remarks are applicable, except on the east side of Lonesome Prairie, where there are heavy surface deposits of sand in depressed basins, and locally thick beds of alkaline soil. Lonesome Prairie itself is, in my opinion, a coal-bearing region, either Upper Cretaceous or Laramie Group, as coal has been found all around it, and with the exception of Sage Creek, being almost destitute of coulees or creeks, would be an admirable experimental ground for artesian purposes.

The Bearpaw Mountains consist of a central granite (trachyte ?) peak, with mountainous ridges radiating from it, consisting of eruptive, igneous, and metamorphic rocks and slates. The northern side has a narrow strip of Jurassic limestones and shales bearing gryphæa, ammonites, and other characteristic fossils which continues to within 5 miles of Fort Belknap. The same formation found in the Bearpaw Mountains continues through the Three Buttes and the Little Rocky Mountains, the strata sloping on every side from the mountains. From thence to the mouth of Milk River it is similar to the north side.

SECTION No. 3.—*The Marias River and northern watershed of the Teton River.*

This section from Snakes Head ridge (which consists of Cretaceous sandstone) to its eastern boundary consists of a rolling prairie with few creeks, there being only four, being a gradual watershed from the Milk River divide and the Sweet Grass Hills to the Marias River. The geology of the Sweet Grass Hills has already been referred to in section 2. From the mouth of Cut Bank Creek to its confluence with the Missouri River, the Marias River, generally speaking, occupies a narrow, deeply depressed valley with high cut bluffs of alluvial and Cretaceous clays and shales, in some places forming bad lands of narrow width. Between the Marias and the British line the prairie often has large upland ponds without inlet or outlet, and which is often the only water to be obtained for many miles. As the altitude of the east and west peaks of the Sweet Grass Hills are respectively 8,400 and 8,200 feet, and the average altitude of the Marias River is at the mouth about 2,750, and at Cut Bank Creek confluence about 3,900, this will give an average of ascent between the summit of the Sweet Grass Hill range and the Marias River of 5,325 feet. As this watershed is perfectly dry most of the year, except in the immediate vicinity of the hills, also the dip of strata as far as I could discern being toward the south and southeast, the mean distance between the two points being nearly 45 miles, there is every reason to conclude that there is a large imbibition of water in this section.

West of the forks of the Marias the country breaks up into wide valleys bounded by high rolling ridges which continue to the foothills of the Rocky Mountains. As the main western line of the Great Northern Railway traverses this section almost midway, I am satisfied the engineers of this road would be able to furnish data of altitudes which would be of great advantage in determining drainage.

The northwestern portion of this section at the head of Cut Bank, Milk, and St. Marys rivers I can give no information regarding, as it is a difficult problem to treat on, and which I do not yet understand myself, especially in the vicinity of St. Marys Lakes.

As regards Badger Creek (marked on map as Marias River, and flowing considerably south in the Rocky Mountains) this creek rises no further south than west of the head of Birch Creek. At this point a low mountain separates it from the North Fork of Sun River, which flows southeastwardly a mean distance of about 38 miles.

De Poule Creek and nearly all of the tributaries of the Teton River take their rise in a mountainous limestone ridge which separates them from the watershed of the North Fork of Sun River.

With the exception of a small section of country near the mouth of Birch Creek which is distinctively Tertiary (by fossils found), and another section near the head of De Poule Creek which I believe to be either Upper Cretaceous or Lower Tertiary, balance of this section is essentially Cretaceous, as proved by the fossils which are found so abundantly in various places.

The south side of the Marias River has distinct features from the north side, the country being more broken, and in places the Bad Lands having a greater width, though no permanent streams enter it after the confluence of the three forks, the Dry Fork and Piser Creek having only pools in the fall. The ridge between the Teton and Marias rivers is not high, except in the vicinity of the Goose Bill, where it assumes the height of a high butte, and the formation there is lignite, showing two or more veins of that material. This lignite formation is exposed on the surface from the principal meridian of Montana on this ridge to the one hundred and eleventh degree west longitude, and belongs to the Upper Measures of the Cretaceous Period, the point of division between it and the Benton Group being clearly seen on the north side of the Teton River, 6 miles northwest of Fort Benton. Similar to the Marias, the Teton River has few creeks on the north side. The geological strata along the Muddy and near the town of Choteau being the Dakota Group No. 1, Cretaceous Period, which gradually disappears under the Benton Group No. 2, and as we approach the mouth of the Marias River higher groups of the Cretaceous corresponding to the Colorado Group appear locally.

Résumé.—The strata of this section may be said to have a slight dip to the southeast north of the Marias. South of this river to the Teton watershed a slight dip to the northeast. From this point south to the Teton River a dip gradually to the southeast, and as you approach the foothills of the Rocky Mountains this dip is more pronounced. In the southeastern part of this section the higher Cretaceous formations make their appearance covering the lower groups, and below the mouth of the Marias along the bluffs of the Missouri River these higher groups continue, till near the mouth of the Little Sandy Creek a coal vein is found containing middletonite, and which I place at the close of the Cretaceous period or beginning of the Tertiary.

It is my opinion that the dividing ridge of the Teton and Marias rivers is the northern boundary of a great geological trough or basin which will be referred to section 4.

SECTION No. 4.—*The southern watershed of the Teton River, the Sun River, Dearborn and Missouri valleys, and part of Smith, Belt, Highwood, and Shonkin creeks.*

The Missouri River traverses this section almost midway, running in a northeasterly direction, the city of Great Falls being near the center. This river enters this section near 47° north latitude and leaves it near 48° north latitude. At or near the southwest corner of township 17 north, range 1 west (near the Halfbreed Rapids), the flow of the river is considerably increased from some source not yet determined. It is almost certain, too, that the underground flow of the Dearborn and Sun rivers is greater than has been supposed hitherto.

At the city of Great Falls commence the great falls of the Missouri River, which, in the distance of 9 miles, makes the river descend 500 feet.

One and a quarter miles northeast of the city limits is the great "Giant Spring," which ejects a volume of water equal to one-half the bulk of Sun River. In the center of the river bed and opposite to the Giant Spring is another spring supposed to be equally as large. These two springs, I judge, increase the volume of the Missouri River about one-tenth. Many surmises have been made as regards the origin of this remarkable body of water. Nothing can be said with certainty, so that I shall only deal with facts from which deductions can be made.

First. The Giant Spring is situated on the south side of the Missouri River.

Second. Its level is about 10 feet above the river at medium stage of water.

Third. It is about 100 feet from the edge of the rocky bank or low bluff.

The bank is not high immediately near the spring, but a little further up the river on the same side about 20 feet of perpendicular rocks are exposed which belong to the Dakota Group, No. 1, Cretaceous period.

Fourth. For a distance of about 300 yards there are numerous small springs in this cliff, which contain in solution so much lime as to form calcareous tufa at their point of exit.

Fifth. There is no limestone in these cliffs.

The Dakota Group cover this section for 27 miles south of this spring, and in that distance the strata have a dip northward of 1,437 feet = 53$\frac{2}{9}$ feet to the mile. That immediately south of this Dakota group are the Little Belt Mountains, which at this locality are limestone (Carboniferous), and the water contained in the creeks issuing from this range sink so much that not one-twentieth part of their volume reaches the Missouri River on the surface.

The Dakota Group here has also a dip to the northwest as in section 9, township 19 north, range 5 east, in sand coulee, the Carboniferous limestone here appearing at the surface, the Dakota Group lying unconformably upon it; whereas in section 14, township 20 north, range 3 east (about 1 mile southwest of the city of Great Falls), the Carboniferous limestone lays 345 feet deep as proved by boring. This will necessarily give a dip of 31$\frac{4}{11}$ feet to the mile between the two points. As the boring is N. 46° W. from the limestone exposure and the other dip being north, this would give a mean dip of N. 23° W., and as the Giant Spring is N. 11° W. from the limestone this would make the center of dip strike the Missouri River three-quarters mile west of the Giant Spring, which is close enough for all practical purposes. No faults or dikes are yet known between the two points.

This would, therefore, account for the numerous springs found in the cliff above the Giant Spring which carry so much lime in solution, but it does not account for the Giant Spring itself, which is far purer, the materials held in solution being mostly of a different character, the organic matter being merely nominal.

The formation of the Giant Spring must also be taken into account. The orifice is wide and deep. In the limpid waters huge masses of rock seem torn asunder by some convulsion of nature. The body of water is immense. Its outflow is above the level of the river, and the purity of the water I have already spoken of.

Another important factor is that the volume and temperature of the water is always uniform the year round, and the outflow is never affected by the driest or wettest seasons.

As another spring exists in the center of the river opposite the Giant Spring and of similar purity, size, and appearance, I can not come to any other conclusion than—

First. That the source of the two springs lies deep.

Second. That these two springs either are situated on a huge dike or fault not visible on the surface, or that they are ejected from some great subterranean body of water which might, by boring on the same strike, be reached at a considerable depth.

If either supposition or deduction is adopted, a line drawn through the two springs and extended southeastwardly to get clear of the neighborhood of the river, would, in my opinion, form an excellent site for a deep boring for water, such site to be about 1¼ miles distant.

About 3¼ miles southeast, in a portion of sand coulee, it has been proved by boring that a short distance below the surface a body of clay exists, which is from 30 to 150 feet thick. This clay extending over the bottom lands of sand coulee for a distance of over 2 miles. This deposit is, however, merely local.

The Dakota Group is visible on the Missouri River to within 5 miles of Fort Benton, where it is overlaid by the Benton Group.

Northward from Great Falls the depression of this great geological basin or trough is still greater, till the northern edge is reached on the divide of the Teton and Marias at the Goose Bill and Knees Hills.

The northern crest of this basin commences at these hills, as stated, thence west to the Muddy, which flows into the Teton, following along or near the Muddy, thence it skirts the limestone mountain foothills of the Rockies southerly to the Dearborn River, then north and east around the Mission Mountains, thence across the Missouri River southeast to a point about 5 miles above Hound Creek, which flows into Smith River, then following the foothills of the Belt and Highwood Mountains to Highwood Creek. The Dakota Group covers the whole of this section eastward and northward toward the center of the basin. True, Square, and Crown Buttes, near Fort Shaw, have a basalt capping, but this is merely local, and has not disturbed the Measures underneath.

From the western slope of the Highwood Mountains the eastern edge of the basin goes northeasterly to the Missouri River, the Dakota Measures being covered by later Cretaceous.

About 2 miles west of Fort Shaw, however, a very large dike traverses the country, running NNW. and SSE., and which can be traced southeastwardly to the Mission Mountains. As Sun River loses considerable of its volume in its course, can it be this dike has some effect on it?

It is also an undoubted fact in northern Montana, that where mountain ranges have their foothills composed of limestone, at or near the point where the limestone is superlaid by other strata, streams running through that section lose sometimes all their water by imbibition, and always do lose considerable of their volume.

Though, as I stated before, the Dakota Group is found on the Missouri River to within 5 miles of Fort Benton, it does not always exist as a surface stratum. On

Highwood Creek, about 6 miles from the Missouri River, on the east side and close to the road is a good showing of the conformability of the contract of the Dakota and Benton groups. From this point to Pueblos Island on the Missouri River the strata dips rapidly, so that at this point the Benton Group comes to the level of the river, and if as reported the Missouri loses some of its volume between Great Falls and Fort Benton, it must be at or near this point. This loss of volume as reported, however, needs confirmation, as I have seens no signs of it.

The Highwood Mountains are composed of eruptive rock, connected with the Bearpaw Mountains by a broad belt of trap and other dikes. The Dakota Group is exposed for a short distance on the west and northwest, and apparently not much disturbed; they are, however, quickly overlaid by the Benton Group with a general dip toward the Missouri River, where more recent measures are superlaid.

Opposite the mouth of the Little Sandy Creek the Missouri flows through bad lands partly cretaceous, but mostly Tertiary on the surface, stupendous in their magnitude, and almost unique in their eccentric forms.

Résumé.—It will be seen that nearly the whole of this section 4 is situated in a great geological basin or trough, and from examinations made of the dip of the strata I am satisfied the great plateau north of the Missouri and Great Falls, the plateau between Great Falls and Belt River, the basin of Flat Creek, and the vicinity of the town of Choteau offer strong inducements for the sinking of artesian wells.

SECTION No. 5.—*East side of Missouri Valley, part of Great Belt Mountains, part of Smith River, and part of Little Belt Mountains.*

No part of this section, in my opinion, offers an inducement for operations, except a small section near Townsend, on the Northern Pacific Railroad, where a small area is covered with cretaceous measures, covering some of the foothills of the Great Belt Mountains, and lying at an angle which would afford means for imbibition of water.

All other parts of this section, if they have any imbibition of water, it would be merely local, as the balance of the section consists of eruptive and metamorphic rocks, Jurassic slates and sandstones in some localities, a large area of Carboniferous limestone often lying vertical, and in Smith River Valley a small area of the Miocene age.

SECTION No. 6.—*The Judith Basin and Arrow Creek.*

This widely known section of the country forms an interesting study from a geological standpoint. Hemmed in by mountains on all sides except the north, the number of geological strata found within its limits are as varied as the isolated mountain peaks and ranges by which it is surrounded.

Around the Highwood Mountains no limestone formation is found on the surface, with the exception of a small impure stratum near Arrow Park. The Dakota Group lie against these mountains on the east and south sides, the strata being rent and distorted in the immediate vicinity by dikes, where the coal vein is frequently vertical. The strata has then a dip of northeast toward the mouths of Arrow and Judith rivers, where they then become superlaid by upper Cretaceous measures, and finally by the Tertiary.

The Little Belt Mountains consist of a granite and trachytic core, with outlying mountains of Carboniferous limestone, traversed by porphyry dikes. On the foothills the Dakota Group comes in, which is coal bearing and can be easily traced the whole length of the range to the Judith Gap to the center of the basin. For the south, southeast, and east parts of the basin the same remarks are applicable. The altitude of the sources of the various confluents of the Arrow and Judith rivers is very near the same, viz, about 5,000 feet, as follows:

	Source.	Mouth.		Source.	Mouth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Arrow River (main stream)	5,000	2,600	Judith River (main stream)	5,150	2,400
Wolf Creek	5,100	2,700	Ross Fork	5,000	3,000
Sage Creek	5,000	3,000	Dog Creek (flows in Missouri River)	[illegible]	2,400
Warm Spring Creek	4,700	2,900			
Big Spring Creek	5,000	3,400			

The average height of mountains are: Little Belt, 8,000 feet; Big Snowy, [illegible],000 feet; Judith, 6,000 feet; Moccasin, 5,700 feet; Highwood, 6,800 feet.

The Judith Gap is 4,650, being a low pass south of the basin.

The general average of the altitude of the basin is as follows: Upper, 4,500 feet; center, 3,800 feet; lower, 2,400 feet.

As stated before, on the slopes of the Belt Mountains, the formation is Carboniferous limestone; this is superlaid by Cretaceous measures which occupy the whole country and part of the lower basin, and which in the section between Arrow and Judith rivers east and northeast of the Highwood Mountains are again superlaid by tertiary measures which extend to the Missouri River, and are known generally as the Arrow River Bad Lands.

Not one-twentieth part of the volume of water which leaves the various mountain ranges reaches the center of the basin on the surface. This is especially characteristic of the streams of the Belt Mountains.

All the measures dip to the center of the basin, when there is a general declination to the north towards the Missouri River.

A special surface feature of the center of the basin is the remarkable low divides between the various streams, the height being so small that sometimes it is impossible to tell when crossing from one creek to another.

Several local deposits are found in different parts of the basin, which I have not yet had opportunity to examine.

Résumé.—From the above remarks it will be seen there is a remarkable imbibition of water in this section at the foot of the mountain ranges; that the center of the basin is nearly level, so to speak; and that the course of the underground currents must be NNE.; consequently, in my opinion, the whole section from Stanford to Lewistown would be an admirable experimental ground for artesian purposes.

SECTION NO. 7.—*The area south of the Bearpaw Mountains as far as the Missouri River, thence to the intersection of the south watershed of Milk River with the Missouri River.*

South of the Bearpaw Mountains the country is much broken between the mountains and the Missouri River, changing into Bad Lands, which extend east to 109° west longitude, and south of 48° north latitude to the Missouri River, after which the remainder of this section may be characterized as rolling prairie.

The whole section, with the exception of the mountains, is Tertiary.

SECTION NO. 8.—*The Muscle Shell River and Armells Creek.*

The neighborhood of Armells Creek is essentially Tertiary, and northward and eastward along the Missouri very broken.

On the Muscle Shell River near the mouth is Tertiary, but advancing upstream the valley is one vast coal field, mostly lignite as exposed on the surface, for there has been no underground exploration work done. This coal field extends along the foot of the Big Snowy Mountains as far as Elk Creek, which rises near the Judith Gap, thence it reaches south as far as the Bull Mountains south of the Muscle Shell River. Westward in this section Cretaceous measures come in which extend to the mountains. The general dip, except in the immediate neighborhood of the mountains, is easterly.

SECTION NO. 9.—*The Big Dry and Elk Prairie creeks.*

This section I have not visited for twenty-three years, so that memory will not serve. The Tertiary and Cretaceous, however, are marked pretty accurately.

SECTION NO. 10.—*The north watershed of the Yellowstone River.*

From the Crazy Mountains northeastward this section is the same as the Muscle Shell, with the possible exception that below Billings the strata may be Lower Tertiary. The fossils I have found above Billings are essentially Cretaceous. The general dip is ENE.

SECTION NO. 11.—*South slope of the Yellowstone River.*

On the northern slope of the Bear Tooth Mountains are the Red Lodge coal mines, belonging to the Laramie Group. Coal mines of the same group are found west of Livingstone. In my opinion a large area of the Crow Reservation is underlaid by the same formation. Eastward of this the lignite deposits are found, which cover a very large area, as by my personal observation they extend as far as the Powder River ranges. I consider that that part of section east of Big Horn River is an extension of the same measures as the Dakota lignite series. A general dip easterly is found in this part of the section.

GREAT-FALLS, MONT.,
December 26, 1891.

ARTESIAN WELLS—FACTS AND THEORIES.

The theory that there is no relation between the pressure and volume discharged from artesian wells is supported by Flenniken & Co., who are manufacturers of a special water wheel adapted for high heads. They have made a study of the Dakota artesian wells for the purpose of designing a wheel to utilize the water (under pressure) from artesian wells for power purposes. They say:

Many inquiries come to us about the power of artesian wells. Some people seem to think that the pressure of a well is different in principle from that of a "head" or "fall." Such is not the case. The pressure in both cases is due to the same cause, a "head."

The hole in the ground is only to obtain a connection with the underground reservoir, which receives its supply from some level, perhaps hundreds or thousands of miles distant, and whose pressure is dependent upon the elevation of the source of the supply above the level of the ground where the well is sunk.

Still there are difficulties in estimating "artesian powers" that are not found in ordinary practice, but these difficulties are not due to any difference in principle of hydraulic action, but natural causes that seldom affect the development of waterfalls, viz. the restricted discharge of the water from the pipe due to the receiving and penetrating a porous rock, through which the water must be filtered, instead of tapping a solid volume, as would be done if the pipe connected to a pond.

The result is that the flow of water, instead of being governed by the pressure or friction on the pipe, as would be the case when a pond or natural surface reservoir is tapped, varies with the porosity of the sand or rock through which it filters. This is the reason that a 6-inch well with 60 pounds closed pressure will often discharge more water when running free than a well of the same size with double the pressure.

It also accounts for the fact that the flow is never up to the full discharging capacity of the pipe; and furthermore, that it does not increase in volume in proportion to the increase in size of pipe, which would be the case if the supply was restricted.

To illustrate: A 6-inch pipe, if connected with a tank or reservoir of water which had a pressure of 100 feet head at the delivery, would discharge about 750 cubic feet per minute (less the frictional loss through pipe); then an 8-inch pipe under the same condition would discharge 1,333 cubic feet, or nearly double, the difference being as the squares of the diameters of the two pipes. In both cases the discharge is limited by the areas of the pipes; but the same rule does not apply to artesian wells, because the porosity of the rock more than the size of the pipes govern the quantity discharged under same pressure. Therefore we seldom find 6-inch artesian well, with a pressure equivalent to 100 feet head, which will flow more than 200 cubic feet per minute; and an 8-inch well under the same conditions will not usually flow more than 30 to 50 per cent more water than a 6-inch well.

These facts lead us to the conclusion that while with unrestricted supply the discharge of pipes is in ratio to the areas or the squares of the diameters, the law does not hold good in artesian practice, though the discharge will be in favor of the larger pipe, owing to the frictional loss being less.

An understanding of these facts will enable those who wish to improve artesian powers to give us such information as will enable us to estimate their powers, especially if they observe the instructions which follow.

The only way to properly develop an artesian power is to take the measurements and pressure of each individual well, for no dependence can be placed on any two wells of the same size, and showing same pressure when closed, developing the same power.

In fact, the power may vary from 50 to 200 per cent, and is pretty certain to vary 20 or 30 per cent.

There are two ways of measuring the power of a well, which we will describe. Let us suppose a well of 6-inch bore. There should be a gate valve on top of the pipe and a nipple above the valve. Below the valve the pipe should be tapped to attach a water gauge which will show the pressure in feet of head. (In the absence of a water gauge a steam gauge which registers the pressure in pounds will do.) First take the pressure with the valve closed, then take it with a 4-inch reducer on the top of the pipe, and follow with a 3½, 3, 2½, and 2-inch reducer, recording the pressure in each instance.

From the information thus obtained, we can estimate the power within a margin of 15 per cent.

A more accurate plan is to measure the flow of water through a weir (as described on pages 16 to 19 of the Flenniken Turbine Catalogue), dispensing with the reducers on the pipe entirely, and throttling the flow with the valve, so as to obtain pressures from one-half to two-thirds of the total pressure, for between these ratios will the most efficient discharge be found.

Send us the width and depth of flow on weir at six or eight different pressures, ranging from one-half to two-thirds of the total pressure, and we will be able to compute the maximum power of the well.

Having done this we can construct a wheel that will develop the highest efficiency, and insure the most profitable use of the water. A careful attention to these instructions will prevent blunders or costly experiments.

The larger portion of the rock passed through in sinking artesian wells is of a slaty nature, which under ordinary conditions does not present serious obstacles for rapid and successful sinking of holes into it by common drilling machinery, but in nearly the whole area of the Dakota artesian basin drillers have encountered what they call "bad ground," from the top to the bottom of the hole. Hardly a well has been put down in the whole country without mishaps or delays of some kind, which in a majority of cases are caused by the peculiarity of the "ground." These thick strata of soapstone and shales that are encountered are generally so soft as to cave in after the drill, and some of the material is a tough, waxy clay, which is forced into the drill hole by the immense pressure on it, rendering it almost impossible to get through it, and to make any progress with safety it is absolutely necessary to protect the hole from caving in by inserting a casing which must follow the drill quite closely. This is the most difficult part of the work in sinking artesian wells. Frequently there are thin strata of hard material scattered in among the shales, through which it is difficult to drill a hole from the inside of the casing large enough to allow the pipe and couplings to freely pass through it. In attempting to force the casing down very frequently it gets fast and can not either be forced further down or drawn up. Then a smaller hole has to be made, and smaller casing put in, which may also get fastened in the same way. Then still another smaller hole must be made, and still smaller casing used. So it happens in many cases only a very small bore can be made when the artesian supply is reached. Drilling tools have been devised to enlarge the bore below the bottom of the casing sufficiently to allow it to be safely and easily lowered as the drilling progresses, but none of these devices have worked well in this hard rock. When suitable machinery is invented to drill and case the hole at the same time, and continue to do so until the artesian flow is reached, I am of the opinion that the cost of sinking artesian wells in the Dakota basin can be reduced at least one-half; but with the present appliances, and the risks and delays which are involved in their use, there is but little expectation that responsible contractors will reduce the present prices, as they must have a good margin to cover accidents which many times can not be foreseen or avoided.

Among the statements made concerning the periodical changes in the flow, pressure, quality of water, and other phenomena connected with several of the artesian wells in the Dakotas is the statement that small live fish have been known to come up with the water from several of these deep wells.

Diligent inquiry concerning the localities of these fish-throwing wells has resulted in confining them to the railroad and city well No. 1 in Aberdeen, S. D. Here we find scores of honest and reliable people who claim to have seen with their own eyes fish come from these wells. No explanation or argument that the fish might have come from some other source can convince them that they can be mistaken in their statements.

The man in charge of the water service of the railroad claims to have seen large numbers of fish in the water tank which had no connection with any other water supply than the railroad well. Persons filling water wagons and barrels directly from the city well, claim to have caught fish coming direct from the well. Children have been seen holding corn poppers, sieves, and netting under the pipe leading from the well, and have caught large numbers of fish in that way.

The following affidavits from respectable business men in Aberdeen are here given:

STATE OF SOUTH DAKOTA, *County of Brown*, ss:

I, William H. Finch, being duly sworn according to law, depose and say that I am a resident of the city of Aberdeen, county of Brown, State of South Dakota, and have been for the past six years. During the season of 1886 I was running a hotel in the city of Aberdeen, located within 100 feet of what is known as the "city artesian well," and within 300 feet of the "railroad artesian well;" that during said year I had occasion to see these wells nearly every day; that sometime during the year of 1886 the railroad well ceased flowing on account of some obstacle getting into the pipe; in the fall of the year a machine was at work opening up this well; there had been made prior to this time a ditch about 2 feet wide and 1 foot deep for the purpose of carrying off the waste water from the well. This ditch, however, had been perfectly dry for several weeks, owing to the fact that the well had ceased flowing. While the men were at work drilling in this well the water commenced to flow, and very soon a large stream was coming from the same. The land all around this well was perfectly dry and had been for a long time. I was at the well and saw the water flowing from the same, and with force sufficient to throw a stream into the air 8 or 10 feet, and it fell in sprays on the ground near the well. I gathered a large number of small fish that came from this water. A large number of people were there and saw the same thing, and picked up a great many fish that had been thrown on to the dry land from the well. There was no possible way that these fish could have been brought there by any other source, as there was no water anywhere near the well, as the land had been dry for a long time, even if there had been fish in the water which formerly filled the ditch flowing from said well.

Also, a few days later, after the workmen had finished the well, at a waste pipe extending some feet from the well, conducting the water into the ditch, I have seen people stand with buckets and catch the water from this pipe, in which there would be a number of the small fish, so that there was no possible way for the fish to get into the buckets only as they came from the well.

During the same year the city artesian well, located within 100 feet of my hotel, was flowing a large stream of water all the time. The city placed at this well a water trough, which was about 8 feet wide, 2 feet deep and 10 feet long, making the top of the trough 3 or 4 feet at least, from the surface of the ground. The water from the well was carried into this trough by means of a pipe running direct from the well, and I have at several different times during the summer caught a large number of fish in this trough, and have seen taken from the trough at least 500 of the small fish during one day. There was no possible way that the fish could get into the trough from any other place, and even had they been left there by other parties, it would have been impossible to have placed the number in the trough, without detection, that were every day carried away from the same during the summer.

Further, that these fish apparently came from the well only during a few days at a time; probably the longest period that fish were caught from the well at one time would not exceed two weeks. Then there would be no fish to be seen for perhaps five or six weeks, when they would again appear.

The size of the fish would usually be from 1 to 2 inches long, perfectly formed, and looked like the common minnow that is found in nearly every stream of water.

Also, that at different times during the year following, up to the year 1890, I have seen fish taken from the well in the same manner above described. The frequency of their appearance, however, seems to be less and less every year.

WILLIAM H. FINCH.

Subscribed and sworn to before me this 10th day of June, 1891.

S. W. NARREGANG,
Notary Public in and for Brown County, S. Dak.

STATE OF SOUTH DAKOTA, *County of Brown*, ss:

I, Orrin S. Cook, being first duly sworn according to law, depose and say that I am a resident of the city of Aberdeen, county of Brown, State of South Dakota, and have been for the past nine years; that I am well acquainted with all of the artesian wells in this city, and during the year 1886, the well known as the "city artesian well," located in Aberdeen, while flowing as usual was discharging a large number of small fish known as minnows. I did not believe at first that the fish could possibly come from the well, and stopped my team to examine the fish. I saw one of the parties take a cloth screen, and, making a sack of the same, hold it under the spout of the well, catching a number of fish in the same. I took a few of them home with me, where they were kept for over a month, and undoubtedly would have lived longer if we had given them proper attention. There was no possible way for the fish to get into the net in any other way only in going out of the well, as there was no other water near the same and no fish anywhere around, with the exception of those that came from the well. I have seen many people who have claimed to have caught the fish in the same manner from the well at different times, and know of my own knowledge that the fish actually came from the artesian well as above described.

ORRIN E. COOK.

Subscribed and sworn to before me this 10th day of June, 1891.

S. W. NARREGANG,
Notary Public in and for Brown County, S. Dak.

If it is a fact that fish do come up with the flow from these artesian veins, the rocks in which they are found must be exceedingly porous, and they must have continuous lines of fracture both horizontal and vertical. The outcropping of the Dakota group of rocks which are exposed on the Missouri River below the city of Great Falls, Mont., reveals the existence of lines of fracture with sufficiently wide spaces to allow fish of the size here mentioned to enter.

If fish have come up with water from these wells they must have come from the lower vein, as both wells are cased to the lower flow. These statements are given as they are made to us, and it can only be said regarding them that they are made by people who there is every reason to believe think they are stating facts. If we admit that fish can exist under a pressure of 530 pounds per square inch and after coming to the surface are alive, with eyes and all the habits of fish at the surface, we have admitted a problem no more difficult to solve than to account for their coming from a source of supply 600 miles distant through rock fissures.

I do not undertake to offer a solution of either of the propositions.

ARTESIAN WELLS IN THE RED RIVER BASIN.

In addition to the great artesian basin of the Dakotas, which is noticed in detail in preceding pages of this report, there is another basin in North Dakota of quite a different character, whose southern end, as determined by recent developments, laps somewhat on the north end of the Dakota or James River Basin, and extends north into British America. This basin we denominate as the Red River Basin. Its southern end, as determined by the investigations, is in the vicinity of Fargo, and follows the valley of the Red River of the North to Lake Winnipeg, in British America. The investigations of this basin are, of course, confined to that portion of the country lying west of the Red River, as this river traverses almost exactly the ninety-seventh degree of longitude, the eastern limit of this inquiry. Assistant Engineer W. W. Follett was assigned the duty of making an examination of this basin, and makes the following report:

REPORT OF RED RIVER VALLEY ARTESIAN BASIN.

JAMESTOWN, N. DAK., *August* 31, 1891.

DEAR SIR: The following is my report on the artesian waters in that portion of the valley of the Red River of the North lying north of Fargo in North Dakota.

The territory covered by this report is about 150 miles long, north and south, by about 25 miles wide, east and west. That portion of it in which artesian water is found lies along the river and back from it for 12 or 15 miles—in some places 20 miles—and is of very uniform surface, falling in the 150 miles from 903 feet above sea level at Fargo to about 810 feet at Pembina, or only some 0.6 feet per mile. The fall from west to east is from 5 to 10 feet to the mile, being less near the river and greater farther back. West of the valley proper the ground rises much more rapidly, being the southern continuation of that ridge which terminates at the north in the Pembina Mountains. The basin extends across the river into Minnesota for a short distance. I did not go into this territory as it is outside the limits of this investigation, but learned by inquiry that there were some wells all along the river in Minnesota, but that the quality of the water was bad near the river. At Crookston, about 18 miles east of the river, I was told there were 18 or 20 flowing wells of good water. I could learn nothing of their depth, size, pressure, or flow. They may be in this basin and may be in another.

The main and lower artesian vein in this valley lies at a depth of between 200 and 300 feet below the surface and is in a drift formation. The water is found in a clean white sand or sandstone. Mr. Swan, who drilled the well at Grafton, and also one at Rosenfeld Junction, in Manitoba, about 15 miles north of the boundary line, calls it "gray sandstone." The shoal-well drillers call it sand. It is quite likely that it is an open porous sandstone, very friable, and containing much free sand. If it were loose sand only it would be impossible to keep a hole open in it. The drillers do, however, except in a few cases where the flow is very free when first struck, go down in it as far as they wish and put in their pipe, using no screen on the lower end of the pipe.

This sandstone is immediately overlaid by red shale or cemented gravel. The upper formations are quicksand, some limestone in places, shale, clay with granite bowlders, and clay. The water is all salty. The amount of salt is small at the south and increases to the north. I could not determine to my satisfaction that there was any increase in the amount of salt in the water as the river was approached or as lower ground was reached. At Grafton it was thought by some that this was the case, but no one was sure of it.

The surface pressure of the water, on east and west lines, was, in Walsh County at least, about the same so long as the rise of the ground was not over 5 feet per mile. When the rise became more rapid the pressure grew less until the water will not come to the surface.

There are above this main vein two or three weak veins from 100 to 200 or 250 feet below the surface. These veins are not continuous. In fact, if the quality of the water in adjacent wells is any criterion, it may be best to say that there are two or three sets of veins above the main flow. One well, say, 150 feet deep, may flow water so bitter and impregnated with minerals that no animal can drink it, while a well near by, of about the same depth, flows good water fit for domestic use. These upper veins are also very much broken up. In places the wells going to the deep or main flow will strike two or three weak flows above it. In others none will be struck. Perhaps a hole will be put down 200 feet, a granite bowlder struck, and the hole abandoned with no water, the rig moved 50 or 75 feet away and a flow obtained at 100 or 150 feet.

These upper veins are in quicksand under clay or bowlder clay. The veins are generally thin, not more than 2 to 5 feet of sand, although in places 25 to 30 feet of quicksand is encountered. They have only 2 to 5 pounds pressure and a small flow, seldom exceeding 5 gallons per minute. The water varies widely in quality, but is generally bitter and impregnated with minerals.

Beginning at the north and taking the several counties in order, the following is a history of the wells, so near as could be learned without a personal visit to each well.

Pembina County.—This county includes the first 32 miles south of the international boundary.

At Hamilton, about the center of the county, a 4½-inch well (see Hamilton well in main report on the Dakota wells) was put down to a depth of 1,560 feet. In this hole a vein of salt water, not flowing, was struck at 174 feet; a flowing vein, furnishing 60 gallons per minute at 300 feet, and another furnishing 125 gallons per minute of brine at 1,241 feet in a rift in the granite. This last flow contains 3½ per cent of salt, or 2,000 grains per gallon. The flow at 300 feet contains about 350 to 410 grains of salt per gallon, but was bitter, as was that struck at 174 feet. The water from the deep vein (the others were cased off) kills vegetation, and is used only for bathing. Its temperature is 41½° F. and the pressure when closed is 27 pounds. The well is not in such shape that the flow can be measured. The 4½-inch pipe is plugged with a long wooden plug having a ¾-inch gas pipe through it with a T on top. One end of the T runs to a bath tub, and the other end has a valve on it and opens to the air. This valve will pass 26 gallons per minute with the gauge on the other end of the T reading 12 pounds pressure. It is impossible to say what portion of the full flow of the well this may be.

At the elevator in Hamilton is a 2-inch well 200 feet deep with small flow, not used. There are ten or twelve 2-inch wells down 175 to 200 feet around in the country near

Hamilton. They all have small flows and are used for stock water. At Bathgate, 6 miles north of Hamilton, there is a small well.

St. Thomas, 4 miles north of the south boundary of the county, has three or four 2-inch wells with very weak flows.

These are all the wells I could learn of in Pembina County. They show that the artesian veins, while underlying the country, are poorly supplied with water. Attempts for wells at various places show that the veins are broken up, pinching entirely out in places. This is especially true along near the Red River. Hamilton lies back 11 miles from it.

Walsh County.—The next county south of Pembina is Walsh. It is 24 miles wide, north and south, and has the best wells in this valley. The number of flowing wells in the county is about as follows:

6-inch well going to deep vein	1
3-inch wells going to deep vein	2
2-inch wells going to deep vein (about)	20
2-inch wells going to upper veins (about)	60
	83

The depth of wells going to the deep or main flow varies from 220 feet up to 300 feet. This flow is always overlaid by cemented gravel and bowlders or red shale, and is in a coarser sand than the upper flows.

Grafton, the county seat, 8 miles south of the county's northern boundary, seems to be the center of the area giving free and large flows. The city has a 6-inch deep well (see "Grafton well" in main report on Dakota wells) put down to a depth of 912 feet. It is plugged up below 330 feet and derives its water from a white sand or sand rock lying under red shale between 270 and 330 feet. It was supposed in Grafton that the flow came from below 500 feet. One log gave it as from 503 to 528 and another as from 511 to 536. The temperature pressure and quality of water all led me to believe that the flow was from the same vein as that of the 2 and 3-inch wells in the neighborhood. I wrote to Mr. A. E. Swan, who put the well down, and he told me that the well was plugged below 330 feet as stated above, and that no water at all was found below 330 feet, except a light flow of brine at 390 feet. The well flows 600 gallons per minute. Temperature 46 ° F. Pressure, 12 pounds, and has 240 grains of salt to one gallon of water.

There are two 3-inch wells in this county. The one at the courthouse in Grafton is 301 feet deep. Water was struck in sand rock under red shale at 281 feet and has a pressure of 12 pounds; temperature 45°, and flow 175 gallons per minute. The flow of this well was obtained with considerable difficulty, as a valve had to be taken to pieces and taken off, some reducers taken out, and a piece of pipe put on to carry the water outside the well house. The flow of 175 gallons was a weir measurement of the full flow of the well.

The other 3-inch well is at Minto, 8 miles south and 3 miles east of Grafton. The water was struck in friable sand rock under cemented gravel at a depth of 209 feet, and the well is said to have a flow of about 175 gallons per minute and a pressure of 12 pounds. The quality of water is the same as at Grafton.

A sample of the 2-inch wells going down to this flow gave same temperature and pressure, and flow of 45 gallons per minute. It was flowing some sand, and I was told that some of the other 2-inch wells flowed more water, probably 60 gallons per minute.

These samples show that the flow here is abundant. The sand, or sand rock, is 60 feet thick, and so free that the water gets through it readily.

Over on Red River, about 10 miles southeast of Grafton, are two 2-inch wells reaching this vein. They are 227 feet deep; water in sand or friable sandstone, under cemented gravel; 12 pounds pressure and 30 gallons per minute flow, with about 300 grains of salt per gallon. In one of them a small flow was struck in quicksand at 190 feet, but none in the other at that depth, although the two wells are only about half a mile apart.

The other 2-inch deep wells are near Grafton and west of there. Those farthest away are 10 miles west of Grafton, or 20 miles from the river. The pressure and flow are less on these than at Grafton, but the water is said to be a little less saline.

I was told in Grafton that the water of this main flow contains more salt as it is tapped further east and is quite strongly saline where struck in Minnesota, across the river.

The shoal wells are scattered all over the eastern 18 miles of the county. They are from 100 to 150 feet deep and are all 2-inch wells. The water is found in quicksand under clay. The pressure is only 2 to 4 pounds, and the flow very small, ranging from 1 to 5 gallons per minute. The quality of the water varies widely; some of it is good for household use and some is bitter and salty.

Attempts have been made for wells in the central part of the county, but have been unsuccessful. At Park River, elevation 983 feet, a well has been put down 400 feet.

The clays which underlie the upper veins of water around Grafton here come to the surface. At 96 feet, 5 feet of sand was struck with a vein of water which came within 30 feet of the surface. This is probably the main vein of the lower valley. A smaller supply under less pressure was struck in 2 feet of sand rock at 300 feet, but no water below this.

Grand Forks County.—This county is 36 miles wide, north and south. There are very few flowing wells in the county. The number is about as follows:

About 6 miles southeast of Forest River, in the north edge of the county, 2-inch wells	3
Three miles west of the river, 2-inch wells	10
At Ojata, 12 miles west of the river and 20 miles south of northern boundary of county, 2-inch wells	2
At Reynolds, on south boundary of county, 3-inch well	1

Total, one 3-inch, fifteen 2-inch wells.

The most of these go down to the lower or main flow. Around Manvel many wells have been put down to an upper flow struck at about 100 feet in quicksand. These are of no account, as they invariably soon choke up with sand and stop flowing.

One of the three wells 6 miles southeast of Forest River is said to be 125 feet deep and flows fresh water. The other two are 160 feet and 230 feet deep, respectively, close to the first, and both flow salt water. I did not visit these wells.

At Manvel I examined a 2-inch well 166 feet deep that gave about 10 pounds pressure, 60 gallons per minute flow, temperature 46°, water salty and bitter, but used for stock. It is too strong for household use. The owner of the well, and others, said that quicksand and first flow was struck at about 95 feet, and that there was no hard material below this point, but that the sand gradually got coarser until the main flow was struck in coarse gravel at 166 feet. This, while contrary to what one would naturally expect, is probably correct, and the water struck at 95 feet is from the main flow, but impeded by the quicksand. This well was a new one put down about two months ago, and has the largest flow of any of the wells at Manvel. The average of the ten in and around Manvel would be about 25 gallons per minute. In all the water is too rank for household use, but stock drink it readily. They are from 125 to 175 feet deep. The vein seems to be pinched out all around Manvel, as none of the wells obtained are more than 3 miles away, and outside of that limit several dry holes have been put down. Six miles southwest of Manvel, on Turtle River, a hole was put down 300 feet, and no water obtained.

I was told there were at Ojata two 2-inch wells flowing a small amount of water. My time was so limited I did not visit them.

At Reynolds the 3-inch well is 218 feet deep and flows about 4 gallons per minute; water salty, not so strong but that it can be used for household purposes.

In the western part of the county several dry holes have been put down. Near Larimore three holes have reached a depth of about 600 feet and no water. At Northwood, 4 miles north of south boundary of the county, and 30 miles west of the river, a hole is now being put down. They are down some 300 feet and have no water. About 3 miles south of the north boundary of county and 22 miles west of the river a hole was put down 200 feet and no water obtained. There are samples of quite a number of fruitless attempts for water in the western part of Grand Forks County.

I could not learn that abortive attempts for wells had been made at or near Grand Forks, but it is fair to suppose such is the case, as there are no flowing wells in that part of the county. There are possibly a few in small wells in the southeast corner of the county.

Traill County.—Traill County is 30 miles wide, north and south, and extends the same distance west from the river. There are a large number of flowing wells in the county, pretty generally scattered over it, except in the extreme western edge. It is difficult to give the number in the county without a detailed examination and visit to each township. The following is approximately the number:

Location of wells.	Size.	No.
	Inches.	
Buxton	8	1
In and near Buxton	2	15
In and near Hillsboro	2	75
In and near Caledonia and along river	3	60
In and near Kelso	2	10
Mayville	6	1
In and near Mayville	2	10
Portland	7	1
Along railroad, south and southeast of Mayville	2	15
Total		188

It is currently reported that there are 400 flowing wells in Traill County. This would give nearly one well to each section throughout the portion of the county where wells are obtained, and it is certain there are not that many. The number might go up to 250 by counting all the weak flowing wells and those which have flowed at one time, but have now failed. The number can not go beyond 250.

In the eastern half of the county the wells run from 125 feet to 175 feet deep, except a few deep wells which are from 250 to 300 feet deep. The flow of the shoal wells is small, probably averaging 5 gallons per minute. The quantity of the water is rather poor. All of it is saline and all of it has other mineral in it, rendering it bitter and, in many cases, unfit for household use. The quality of the water near the river is said to be better than that farther west. The temperature of all is 46° and the pressure about 10 pounds, varying, however, from 7 pounds along the river to 20 pounds in some of the shoal wells at Hillsboro near the center of the county. The water is generally found in gravel under blue clay; sometimes quicksand is encountered, but the flow, if any is obtained, is small and of poor quality.

As in Grand Forks County the water-bearing strata seem to be much broken up. In Hillsboro are some ten wells, all flowing, yet a dry hole was put down 715 feet at the elevator, the last 115 feet in Laurentian granite, and two or three other dry holes were had in different parts of the town. From all parts of the county failures are reported.

North of Hillsboro are four deep wells. One of them is 262 feet deep. No water was struck until 259 feet was reached. Then water in gravel under blue clay, flowing 67 gallons per minute; temperature 46° pressure, about 30 pounds; water saline, but good for stock and household. The other deep wells are similar both in material passed through, flow, and pressure, although their flow is smaller than that of this well.

All the wells around Buxton, in the northern part of the county, are said to be between 300 and 400 feet deep, and to flow from 8 to 10 gallons per minute. It is likely these depths are too great, but it may not be. I did not have time to visit Buxton.

The wells around Kelso, near the south side of the county, are from 110 to 125 feet deep, and have a very light flow, not over 2 or 3 gallons per minute.

In the extreme south edge of the county, and 10 miles west of the river, is a 4½-inch well recently put down to the depth of 306 feet. There was an old 2-inch well on the place 206 feet deep with very small flow, and this one was put down to obtain, if possible, a larger flow. At 305 feet a vein of sand and gravel 1 foot thick was struck, which furnished at first a little water, coming up in the pipe to within 21 feet of the surface. The pump was put on to try the volume of water which could be pumped. Sand commenced to run and the water pressure to increase until in 48 hours the well was flowing 35 gallons per minute from a pipe 4 feet above the ground, and had a pressure of 2 pounds. The temperature is 46 degrees and the water is very hard, but slightly saline, and is good for household and stock. This is the only well I could learn of in the southern portion of Traill County which went down to this lower vein. It is doubtful whether or not the vein is continuous. As seen in the record of this well it was almost pinched out here.

The 6-inch well at Mayville, near the western part of the county, is 357 feet deep. The strata passed through were clay and then rock-clay and gravel mixed with some cemented gravel. Two or three light flows of water were obtained from thin veins of quicksand. The final flow is from sand, but is small. It could not be measured as it was attached to mains and a tank, but as near as could be learned from inquiry it was some 60 gallons per minute; temperature, 46 degrees; pressure, 8 pounds; quality, salty, but used for household.

The 2-inch wells around Mayville vary from 200 to 375 feet in depth, and have flows of 30 to 40 gallons per minute. All are saline, but used for stock and men.

The 7-inch well at Portland, 3 miles west of Mayville, is 560 feet deep. The strata passed through are clay, hard pan and rock-magnesian clay, quicksand hard pan, quicksand, and then water in hard gravel. Two small flows were obtained from the quicksand strata. This well also could not be measured, as it was attached to a tank and mains. The flow is larger than that of the Mayville well. Some gave it as 275 gallons, but this is probably too high. It has at least 150 gallons per minute flow, pressure 8 pounds, temperature 46 degrees, quality saline, but good for household use. It supplies 300 people. There are no other flowing wells in Portland.

About 8 miles southwest of Mayville is a 2-inch well 440 feet deep. There was a light flow struck in quicksand at 375 feet. The main flow is in sand under hardpan, flow 30 gallons per minute, pressure about 10 pounds, temperature 46 degrees, good water, only slightly saline. This well has the largest flow of any south of Mayville.

Near Blanchard, 8 miles north of the south line of the county, are some eight or ten wells from 160 to 350 feet deep and all having fair flows, probably 10 or 15 gallons per minute, all good water.

The formation in the western part of the county is considerably different from that in the eastern part. The different veins of water become more widely separated and the intervening material becomes harder and more stony. It is called by the well men "a hard country to drill in."

Cass County.—Cass is a large county, being 42 miles wide north and south and extending 42 miles west from Red River. The portion, however, which lies in this basin is in the northeastern part and north of Fargo and is 25 miles wide, north and south, and extends 20 miles west from the river. There are some ten or twelve wells in the southwestern part of the county, but they are probably in a separate artesian basin (the "Tower City" Basin), and should be treated in a separate report.

The number of flowing wells in the northeastern part of the county is about as follows:

Location of wells.	Size.	No.
	Inches.	
Grandin and the two townships at north side of county	2	30
Gardiner and the two townships next south	2	35
Arguswille, and near there	2	15
Hunter and east	2	25
North of Casselton, along railroad	2	15
Total		125

It is currently stated that there are "several hundred" flowing wells in this county, but I could not materialize them. The number given above is about correct, barring the few in the southwestern part of the county, which, owing to their depth, flow, pressure, and quality of water are thought to be in another artesian basin.

All of these 125 wells stop at the first flow obtained. Whether there is a deeper flow at all places or not I am not prepared to say, but it is doubtful. In a few places holes have been put down 300 to 400 feet without getting water. The wells vary in depth from about 200 feet in and around Grandin to about 120 feet in Gardiner. When at Grandin I could learn of but one well, the 4½-inch well in the extreme south edge of Traill County, which went down to the lower flow. At Fargo and at Mayville it was reported that there were several between Grandin and the river which went down to it, but diligent inquiry failed to find them.

The flow of these wells is all small; probably two gallons per minute would be about the average. The pressure on all is light, not over 2 pounds in any, and in some decreasing to barely enough to cause the water to flow. The water is all saline, none of it is pure, and none of it very bad. The drilling in the eastern part is easy and wells fairly sure except close to the river. There many dry holes have been put down. In the western part, along near and east of the railroad running north from Casselton, the drilling is much harder, as much gravel and bowlder clay is encountered. The wells are deeper than near Grandin and Gardiner, but the flow is stronger. At Hunter is a two-inch well, belonging to the town, 345 feet deep, flow about 15 gallons per minute, pressure 8 pounds, water clear and good. The other wells near Hunter are deep, nearly all reaching 300 feet, and the average flow would probably be 6 or 8 gallons per minute.

Around Arguswille the flow is small and pressure almost nothing. One 2-inch well at Harwood, 8 miles northwest of Fargo, barely flows.

In Fargo no flowing wells are obtained unless in depressions. This same vein underlies the whole country here, however, at a depth of from 160 feet to 180 feet, the water rising to within a few feet of the surface and being slightly saline.

The total number of wells and aggregate flow in this basin are as follows:

County.	1 inch.	6-inch.	4½-inch.	3-inch.	2-inch.	Aggregate flow.
						Gallons.
Pembina			1		17	165
Walsh		1		2	60	1,950
Grand Forks				1	15	370
Traill	1	1	1	1	180	1,800
Cass					125	300
Total	1	2	2	4	427	4,585

This total of 4,585 gallons per minute means 20 acre feet per day, or 7,300 acre feet per year. As much of the flow is estimated, it may be possible that the whole flow of the wells is 10,000 acre feet per year from an artesian vein that is known to be 125 miles long by at least 15 miles wide, or an area of 1,875 square miles, or 1,200,000 acres. This 10,000 acre feet spread over this area would be one-tenth of an inch deep. In other words, the combined flow of all the wells, provided they ran constantly, would only lower the water in the sand rock one-tenth of an inch if it were a continuous sheet of water. The fact is that the wells do not average flowing more than half the time. It is needless to say that the supply is not visibly decreasing except in a few wells that are in quicksand where the water does not have free access to the pipe.

FORMATIONS.

While it is the province of our geologists to discuss the stratigraphy of the country, it seems best in this connection to give, as a matter of record, the notes which I obtained of the formation in the valley.

The Archæan rock underlying the valley is a gray rock called by the Canadian geologist "Laurentian granite." It is claimed by some that this is not a granite, but a very hard impure sandstone. Whatever it is, its presence is constant under the valley wherever holes have been put down deep enough to reach it.

Location.	Elevation.	Was struck at about—	Sea level.
	Feet.	*Feet.*	*Feet.*
Moorhead	908	550	358
Hillsboro	901	600	301
Grafton	837	908	— 71
Hamilton	824	897	— 73
Rosenfeld Junction	780	1,035	—255
Winnipeg	750	1,000	—250

It is stated that the granite is below the surface. This shows an average dip to the north of 3 feet to the mile, about five times the dip of the present surface.

With the exception of the well at Hamilton, no flowing water is found in this rock although it was penetrated some 1,250 feet at Moorehead, 115 feet at Hillsboro, and 650 feet at Hamilton. At Grafton and at Rosenfeld Junction work stopped when the granite was reached. The rock at Moorhead and at Hillsboro seems to lie level, but at Hamilton the stratification is supposed to be tilted up on edge, as shown by the fact that the drill, when striking veins of mica, would go off one side of the hole, making a crooked hole. This may account for the fact that water is obtained in the rock there, or there may be vertical seams in the granite, reaching to the surface. The water at Hamilton is found in a sand vein 1¼ feet thick 1,241 feet below the surface of the gronud, and 344 feet below the top of the rock. This, as stated above, may be simply a rift extending to the surface of the rock and drawing water from the artesian vein far above.

Overlying this rock is a thin stratum of sandstone not always present. It contains no water.

Above the sandstone is a deposit of shale of varying thickness. At Rosenfeld Junction it was 160 feet thick; at Hamilton, 130 feet; at Grafton, 200 feet; at Hillsboro, about 200 feet thick; at Moorhead, 105 feet thick. This shale all contains sand. At Rosenfeld Junction the upper 50 feet was so sandy that it was classed as "sandstone."

On top of the shale comes limestone of varying degrees of hardness and of varying thickness. At Rosenfeld Junction it was 380 feet and furnished a flow of water 3¼ per cent salt at 300 feet below its upper surface. At Hamilton it was 455 feet thick; at Grafton, 310 feet; at Hillsboro, a little; and not present at Moorhead.

Above the limestone comes more shale of various colors and degrees of hardness. These shales vary in thickness, but come up to the sand or sandstone, which furnishes the main artesian flow. They are thickest to the north, being 350 feet thick at Rosenfeld Junction, and apparently coming so high up as to entirely pinch out the artesian sandstone, being there immediately overlaid with bowlder and bowlder clay, and coming within 145 feet of the surface. At Rosenfeld Junction, Hamilton, and Grafton a light flow of brine was found in this shale, but of small pressure and amount.

The artesian sand, or sandstone, lies on top of this shale. See page 2 of this report for a discussion of the material and composition of this sandstone. It varies widely in thickness in different places, and is, as mentioned several times in this report, sometimes entirely wanting. At Rosenfeld Junction it is wanting. At Hamilton it is 4 feet thick, and seems to take the form of quicksand. At Grafton it is 60 feet thick. At Hillsboro it is thin, wanting in one hole. At Grandin it is only a foot thick, and seems to be gravel. At Moorhead it takes the form of quicksand, and is

70 feet thick. Along the western edge of the basin it varies widely in thickness, and seems to be in many cases sand or gravel.

This artesian sandstone is overlaid in nearly all cases by cemented gravel, or red shale, especially in the northern portion of the basin. At Hamilton it was overlaid by 6 feet of cemented gravel (locally called "hardpan"); at Grafton by 13 feet of red shale; at Hillsboro it was overlaid by clay; at Caledonia by red shale; at Moorhead by blue clay.

Above this cemented gravel or shale comes clay and bowlder clay. The bowlders are granite and very troublesome to drill. The weaker flows are found in veins of quicksand scattered through the clay. The thickness of these quicksand strata vary; frequently they are not present, and at times become 25 to 30 feet thick.

Above this bowlder clay comes blue clay without bowlders, then yellow clay, and then soil.

These are, in a general way, the strata found in the valley. Reference to the log of wells examined in this valley will show considerable variations from these given, and, in a few cases, entirely different formations. These are, in general, true for that portion of the wells located on the flat country near the river.

About 20 miles west of Red River is a strip of "clay country," 3 or 4 miles wide, running through all the counties covered by this report. At the international boundary it is 25 miles west of the river, and at Gardiner it is 15 miles. East of this clay strip it is very difficult to obtain "surface" wells—that is, shoal wells from which the water is pumped. In many places no water will be struck before the upper weak artesian veins are touched, and in others water will be found seeping in through the clay, but so bitter and impregnated with minerals that it is unfit for use. West of this ridge, however, the subsoil becomes more sandy, and sweet water is found in abundance at a depth of 15 to 20 feet. This is true for the next 10 or 15 miles west, or until the country begins to rise into the Pembina ridge. The elevation of this country is from 100 to 200 feet above the river east of it. It is quite likely that this sandy country supplies the upper or weak veins in the valley to the east. It is not exact to say that the clay strip is the cropping of the blue and yellow clays below the surface in the lower valley, as the clay is here as thick, or thicker, than east, but it is evidently the western terminus of these clays.

West of the sandy country and at about the eastern edge of the Pembina Ridge is found the bowlder clay. Further west is a gravelly country, and then a sandy country running into a clay underlaid by shale. For 10 or 12 miles southeast of Langdon, 1 miles south of the international boundary, and 60 miles west of the river, and some 700 feet above it, the railroad cuts all go down into shale.

These facts seem to point to the inference that the gathering ground of this water is on this sandy ridge. The fact that the pressure on each and west lines does not grow greater as the river is approached, although the country is lower, would indicate that the water came from the west. The fact that the pressure grows less as one comes south, until at Fargo the water will not come to the surface, would indicate that this ridge is the gathering ground as its elevation above the river grows less to the southward.

I attach detailed records of all wells examined in the territory covered by this report, arranged as near as possible in the order in which they are referred to in detail in this report.

Yours truly,

W. W. FOLLETT,
Assistant Engineer.

COL. E. S. NETTLETON,
Chief Engineer, U. S. Department of Agriculture.

In addition to the wells reported on by Mr. Follett there are many others of the same class scattered over the settled portions of the Dakotas. This basin is probably the most extensive of any lying in the drift that has yet been discovered in the Dakotas. A smaller one exists in the southeastern part of South Dakota, which was in part examined in the summer of 1890 and reported on by Prof. Updyke. This basin has the same general characteristics as the one under consideration except the quality of the water is much better. There are other small artesian basins in South Dakota which were not examined for lack of time. I think it is safe to say there are at least 1,500 of these small flowing wells in the two Dakotas. The number is fast increasing, as the cost is but little compared with the value they are for the use of the farm. As yet but little irrigation is done from the surplus waters that many of them afford. As a general thing the proper stratigraphic conditions exist in many of the broad valleys and low flat sections of the Dakotas for an artesian supply of this character. During the processes of filling and leveling up of the bottom of the inland lake or sea which at one time occupied this country there were thick layers of mud and clay deposited on the top of fine beds of sand and gravel, and then another layer of perhaps fine sand, which is capped again with an impervious alluvium, forming alternating beds of pervious and impervious materials, one bed being capable of imbibing and holding the water, the other preventing its upward or downward escape. If these strata are inclined a little or come in contact with the surface water or with ground water that has permeated the top soil of the higher country, the result is almost certain to be the formation of an artesian basin. These conditions exist in many sections of both North and South Dakota. Considerable of the surface of the coteaux and table lands are covered with a gravelly and porous soil and subsoil which imbibes water rapidly. Besides there are thousands of lakes scattered over the surface, having an area from 5 to 500 acres each, into which the surface water is drained instead of running into the river and creek channels to be carried away into the larger rivers. These coteaux and table lands are the receiving grounds and sources of supply for the drift wells.

ARTESIAN BASIN AT MILES CITY, MONT.

This artesian basin was examined by Mr. Follett, whose time for this purpose was limited to a few hours, or the time between railroad trains, while on his way to Great Falls. Fortunately the contractor was found who put down most of the bores in this basin, who proved to be competent and answered most of the questions concerning each individual well.

Following up the valley of the Yellowstone we find the water-bearing rock in this basin rises rapidly towards the surface, and is finally exposed at Billings; at least a section of 90 feet of it stands above the surface of the river at that point. Further west the exposed section is still thicker.

There are two means by which water may be supplied to this basin. One is through the upturned strata which lie to the south and west, and which are exposed to the surface waters that fall on that country. The other is from imbibition of the water of the Yellowstone River as it traverses an eroded channel 100 miles or more in length, which has cut its way through the entire section of the rock forming this basin, thus exposing all of its strata to the surface and underground waters in the valley. It is quite probable that should this rock be of the proper character to hold and transmit water a stronger flow and pressure will be found in the lower section of the valley, but on account of the strata inclining in an easterly direction so much more rapidly than does the surface the great depth will likely render it impracticable to reach water within a distance that will justify for artesian well purposes.

For additional information regarding this artesian basin, see well No. 91, and the following report of Mr. W. W. Follett, assistant engineer.

REPORT ON MILES CITY, MONT., ARTESIAN BASIN.

WASHINGTON, D. C., *October* 24, 1891.

DEAR SIR: At Miles City, Mont., on the Yellowstone River, is a small local artesian basin known as the "Miles City Basin." It is only about 45 miles long by 2 or 3 miles wide, and is confined to that portion of the immediate valley of the Yellowstone extending from 35 miles above Miles City to 8 or 10 miles below. In this area are some thirty wells with an average flow of about 10 gallons per minute. Temperature 57 degrees, and pressure of from 4 to 8 pounds. There is one 6-inch well in Miles City, only flowing 6 or 8 gallons per minute. The others vary some in size. The most of them are 2½-inch wells. None are smaller than this.

The depth of wells varies from 160 feet up to 500 feet. The sand rock furnishing the water seems much broken up. It may be that its form is about the same as the supposed form of the water-bearing sand in the Meade County, Kans., artesian basin—that is, folds of the sand rock interlap with the shales.

The following is the record of a well about two miles southeast of Miles City. This is said to be an average well fairly representing those in the basin. Mr. Beck, the owner, put down the greater part of these wells, so is well informed as to their depths, etc. Much of the information given in this report was obtained from him. This well is No. 104 of the Main Report on Artesian Wells of the Dakotas.

Owner of well: O. C. Beck.
Location: Sec. 34, T. 8 S., R. 47 E. Montana principal meridian. Near Miles City, Mont.
Put down in June, 1886.
Size of well: 2½ inches.
First flow struck at 250 feet; 1 gallon per minute.
Second flow struck at 300 feet; 2 gallons per minute.
Third flow struck at 393 feet; 5 gallons per minute.
Pressure, well closed, 7 pounds.
Flow: 5 gallons per minute.
Temperature: 57 degrees.
Quality: Water soft, but with some mineral in it; will not rust iron.
Used for irrigation. Has irrigated one acre of garden.
Cost: $1.25 per foot.

Strata passed through.

	Thickness in feet.	Total feet.
Adobe soil and subsoil	19	19
Gravel with surface water in bottom	21	40
Hard sand rock	2	42
Slate or hard soapstone, hard and soft streaks	18	60
Sand rock with water not flowing	5	65
Slate or hard soapstone and hard and soft sand rock, alternating thin layers of each	185	250
Sand rock, light flow (at 300 feet flow increased)	50	300
Shale	93	393
Brownish red sand rock, 5 gallons per minute main flow	63	456

Bottom on shale.

	Feet.
Elevation of ground above sea	2,343
Elevation, top of main flow	1,950
Elevation, bottom	1,887

The sand rock is nearly all soft, and all wells flow sand for a day or two after water is struck. There are hard streaks in the sandstone varying from a few inches to 6 or 7 feet in thickness.

Examination of this log shows that there are several upper veins of sandstone having water under low pressure. In other wells some one or other of these strata are more open and furnish the main flow.

The water has a mineral taste, but will not corrode iron. In this well the pipe which had been in use five years was just as perfect as when first put in.

There is not enough data obtainable to make it possible to give a very probable conjecture as to the origin of this water. The fact that water is found for a limited distance only in the valley of the Yellowstone would lead one to suppose that the water came from a gathering ground either north or south of the river and that the vein crosses the valley here, giving a flow wherever the ground was so low that the pressure on the water in the rock was sufficient to force it above the surface. I could not learn that this rock cropped out either north or south of the river, but the formations are so much broken up here that it might easily crop and not be noticed, especially as the rock itself is so broken up and interfolded with shales. It may be that this is a cropping or uplift of the main Dakota sandstone, although the color (brownish red) is not the same as that of the Dakota. It is known that the latter stone crops in the southeastern part of Montana, and this may be a part of it.

The supply of water seems to be constant. The increase in wells does not affect any appreciable decrease in the flow of existing wells. There is not enough water to use for irrigation, and its use will be limited to the household and to the watering of stock.

Yours, truly,

W. W. FOLLETT,
Assistant Engineer.

Col. E. S. NETTLETON,
Chief Engineer, U. S. Department of Agriculture.

SUBTERRANEAN WATERS IN THE YELLOWSTONE VALLEY.

In addition to the investigation of the artesian basin at Miles City, a hasty reconnaissance was made of the Yellowstone Valley between Glendive and Livingstone, a distance of about 340 miles. The valley between these points is from a half to 8 miles in width. On each side is a line of bluffs from 100 to 300 feet high, whose faces are irregular and precipitous. The land in the valley is most of it considerably above even high water in the river. To irrigate the most elevated part of it by common methods will require long lines of expensive canals, as the grade of the river is so slight, except in its upper portion; besides, every now and then the rocky bluffs project into the valley to the river's edge; or, in other words, the largest bodies of irrigable lands lie in cove-like localities which are encircled by the high bluffs which close into the river, and to reach the middle of these fine tracts of land with an irrigating canal will require building for many miles—in some instances along the rock face of the bluffs.

The time will undoubtedly come when considerable of these lands will be irrigated by ways and means which would now make it too expensive for the common farmer to adopt. The land commissioner of the Northern Pacific Railway has had the question examined of the practicability of utilizing the water of the Yellowstone for irrigating the lands in the immediate valley as well as the table lands lying back from the river and above the bluffs. He has given me permission to copy from a report made by special examiner and engineer, Mr. R. J. Perry.

Speaking of the canals in operation in this part of the valley under consideration, Mr. Perry says:

> The only canals in operation east of Livingston are those in the valley above Billings, except one or two small ones along by Stillwater and Merrill. . . . It will be difficult to take water from the Yellowstone River between Custer Station and Glendive for two good reasons: First, because the river has so slight a fall, and, secondly, because none of the several widenings of the valley are large enough to attract would-be canal builders to invest large sums.

Mr. Perry gives the gradients of the Yellowstone River as follows:

	Distance.	Total fall.	Fall per mile.
	Miles.	*Feet.*	*Feet.*
Cinnabar to Livingston	51	691	13.55
Livingston to Billings	116	1,378	11.8[illegible]
Billings to Custer Station	[illegible]	[illegible]	7.[illegible]
Custer Station to Miles City	94	372	[illegible]
Miles City to Glendive	78	[illegible]	3.[illegible]

Mr. Perry speaks of two or three canal enterprises above Glendive, where it is possible to irrigate in all about 50,000 acres. He remarks that owing to the slight fall of the river these canals would be from 30 to 40 miles long and would encounter much expensive work. In view of the difficulty and expense of utilizing the Yellowstone River and the smaller streams for irrigating several tracts of fine land in the valley of these streams, Mr. Perry has called the attention of the Land Commissioner to the possibility of irrigating these lands by water raised by mechanical means.

His plan is to raise to the surface the underground waters, which are to be found at shallow depths and in large quantities in that vicinity, by means of the Hoffer vacuum pump, manufactured at Greeley, Colo. He describes a pump of this kind which he saw in operation. He says the pump—

> is located at Rosebud Station on the Yellowstone, and is a 1,000 gallons per minute pump, or 85 miner's inches of water, and would irrigate, according to the table of estimates, 100 acres of land, while the maker claims it would serve 170 acres.* . . . I am sure the maker's estimates are too great; 85 miner's inches will not serve 170 acres of crops. I saw this pump at Rosebud in operation at two different times during the past season, and measured the water and found it was raising 1,000 gallons per minute, or 85 miner's inches. It it is owned by Smith & Bowles and cost them nearly $1,500 set up. The pump has no cylinder, piston, wheel, pulley, or belt, no machinery of any kind, simply a large boiler to furnish a large volume of dry steam to the pump. Steam goes direct to the pump. A jet of cold water condenses it and the vacuum thus formed is filled with water from the river by simple atmospheric pressure, the water flowing out into the ditch by gravity. When in good working order the only thing to do is to feed the fire, keeping a steam pressure of from 20 to 40 pounds to the inch, which gives as good results as a higher pressure. The water by this pump is raised 21 feet.

Mr. Perry estimates the cost in Montana of pumping water with a 2,000-gallon Hopper pump for thirty days, twenty-four hours a day, or 60 days at twelve hours a day, lifting the water 20 feet, to be as follows:

80 tons of Montana coal, at $2 a ton	$160
Interest at 5 per cent on total cost of $2,000	100
One man, two months, at $35 a month	70
Sundries	10
Total	340

Which is $1.60 per acre for water, sufficient, theoretically, to cover in one month 210 acres 15 inches deep.†

While these estimates are considered conservative as to what can be accomplished and the cost per acre for the railroad company to secure water for irrigation purposes, yet it is a question, even if the cost is no more for the individual, if it would in practice pay to raise water in this way for common farming purposes. The pioneer farmer is generally unable to put so much extra ready cash into his farming operations as would be required in the purchase and operating expenses of such a plant.

It will undoubtedly pay to raise water by steam, wind, and animal power for gardening and similar purposes, where the net value of the products from an acre greatly exceed the cost of the labor and seed. The same may be true when an artificial application of water will save a common field crop that would otherwise be lost by drought. As the country becomes more thickly populated, the agriculturists more fore-handed, and when they have learned by experience how to economize in the use of water, irrigation by water raised in these ways will, without doubt, be resorted to which at the present time is wholly impracticable, and which even the most sanguine dare not now predict concerning the natural developments by irrigation.

---

*Mr. Perry estimates the miner's inch to be equal to 11¼ gallons per minute, and that 100 inches are required to serve 120 acres of land in the Yellowstone Valley. This amount of water would, during the irrigating season, say 90 days, if it was supplied constantly during that time, cover 120 acres 40 inches deep. Of course there would be considerable loss by evaporation and absorption by the soil, etc., so a large percentage must be deducted from its useful effect for irrigation purposes. Suppose we say that one-half be deducted, we then have 20 inches of water in addition to the natural rainfall, which is an ample supply, and this can without doubt be obtained by means of a good storage reservoir.

†This estimate being made for the railroad company the price of coal is probably considerably under what it would be if the usual freight charges were added.

SPRINGS AT THE FOOT OF THE EASTERN SLOPE OF THE MISSOURI COTEAUX.

An examination of the probable amount of irrigation that can be done from the perennial springs which lie at the foot of the coteaux on the west side of the valley of the James River, was made by W. W. Follett, assistant engineer, who makes the following note:

There were a small number of springs suitable for irrigation found lying along the eastern edge of the coteaux in Ts. 126 to 145 N., Rs. 65, 66, 67, and 68 W., in McPherson County, S. Dak., and Dickey, Lamoure, Stutsman, Wells, and Foster counties, in North Dakota. There are also many small springs in the bottom of the long depressions, or coulees, as they are locally termed. These furnish water amply sufficient for stock use, but not enough for irrigation. Were there enough water, it could not be used for irrigation, as it could not be gotten out of the coulees onto arable land. The only places where springs can be utilized are along the eastern edge of the hills, where the smooth plains country comes back to them. Here, if water can be found in sufficient quantity, it can be utilized.

In T. 128 N., R. 67 W., McPherson County, S. Dak., in sections 17 and 31, are two springs. From the one on section 31 I last month made surveys for a ditch to carry the water out onto land belonging to Ira D. Clark. There is plenty of fall and the water can be gotten onto the land at small expense. Water enough for from 800 to 1,000 acres can be obtained, and the land to be watered lay in excellent shape for irrigation.

In section 18 at least as much more water can be obtained and good land lies below it. This is more of a marsh than is section 31 and more work would have to be done developing the supply. A good stream, probably 2 cubic feet a second, was running away from the marsh when I was there. It is not level, but lies up on the hillside at quite an angle. In a marsh of this kind I am of the opinion that the water supply can be largely increased by digging ditches back into it, thus relieving the back pressure on the water and allowing it to flow freely. I have seen in New Mexico good strong springs, furnishing water enough for 600 to 800 head of cattle, formed in this way from a place where the only indication of water was a little green vegetation; I can see no reason why this development work should not work on a larger scale in these marshes lying upon a hillside. Of course a marsh which lies flat may be made such from a very limited supply of water, but one on a hillside with water flowing from it must be supplied by a water-bearing stratum behind it.

Going north from the springs mentioned, the next were two springs about 3 miles north of the State line, in Dickey County, N. Dak. Only 200 or 300 acres could be watered from these; not more.

In T. 131 N., R. 65 W., are three springs. One of these (which is in fact two close together) is two large marshes lying well up on the hillside. It is uncertain how much water could be developed from these; at least enough to water 400 or 500 acres, and probably more. The other two are smaller, but together would probably water 300 or 400 acres. Good land is near all of these, and lies low enough and with sufficient slope to be easily irrigated.

In T. 133 N., R. 65 W., Lamoure County, N. Dak., is a long draw with running water fed by springs. It is hard to tell how much water would be gotten from this—at least enough to water 500 acres. The land below lies in good shape for irrigation.

From this point north to township 144 north the country breaks up; both the range of hills and the plain disappear in a rolling, broken country, good for grazing, and a fair farming country when rain is had, but too rolling to irrigate. There are no large springs in this stretch of country.

In Sec. 16, T. 144 N., R. 67 W., Stutsman County, there is a large marsh with water running away from it. Probably enough for 300 or 400 acres could be gotten here. Good land lies in proper shape for irrigation 2 miles below it.

On the east side of the Hawks Nest, in Sec. 35, T. 145 N., R., Wells County, is a running spring which will irrigate 300 or 400 acres of good land near.

These are all the available springs in the country examined, or for several miles north and south of it, giving water enough for 3,500 to 4,000 acres of land. This is without reservoirs for the storage of water, using it directly from the springs. The conformation of the country is such that reservoirs of large capacity can not be cheaply built. Small ones can, however, be built out on the smooth land, making them long and narrow with their long axes at right angles to the line of greatest fall of the land, being practically wide on bank ditches. These would store the night flow and that of days when irrigation would not be going on, and thus largely increase the capacity of the springs. By such cheap reservoirs as these the springs could be made to serve 6,000 acres.

There is in all the draws running back into the hills a good spring flow of snow water and summer floods of storm waters. There are no suitable reservoir sites for this water, as the average fall of the country is too great, but some of the snow waters might be used to advantage for direct irrigation, soaking the land thoroughly about seed-time. As seen on the Richards farm north of Huron, this method of irrigation will go far towards insuring a good crop. The nature of the soil in this country is such (a mixed clay and sandy loam with impervious clay subsoil) that it will hold water for a considerable length of time, and much benefit can be derived from irrigation at any time of the year. Care must be exercised, however, to not over-irrigate. The soil must not be given more water than it can easily take up. If enough is put on to flood the land it will cause the soil to bake and become hard, and will leave it in worse condition than it was before being irrigated.

The formation from which this spring water comes is a gravel intermixed with large bowlders of granite. The water in the wells on the plains east of the springs is found in sand below clay and is generally artesian in its character, but not rising to the surface.

The source of the supply is the hills or *coteaux* to the west, being local drainage. The springs are all lowest in July and August, but increase their flow in September, although that is generally the dryest time of the year. This would indicate that the gathering ground is at some distance, the water coming in September being, perhaps, the snow water of the previous winter. This is an inference not sufficiently supported by facts to make it worthy of much credence. It may be correct and it may not.

Lying immediately west of this section are the Missouri *coteaux*, which have an elevation of two to three hundred feet above the western edge of the plains country west of the James River. On these *coteaux* are hundreds of small lakes which have no visible outlet. The water which falls on this elevated section of country is not carried off in surface drainage channels, except a few on the outer edge, which extend only a short distance into the *coteaux;* therefore, the precipitation that falls on this country that is not lost by evaporation is either absorbed by the soil or finds its way into these lakes.

In some respects this elevated source for an artesian supply resembles that on the west side of the Red River artesian basin, and if the same alternating beds of clay and sand are found here as occur in that basin, we might expect a similar condition to exist that would furnish flowing artesian wells. But the records of the borings of the deep artesian wells along on the eastern base of these *coteaux*, through nearly the whole length of South Dakota and a considerable distance into North Dakota, do not reveal the existence of a drift strata, as is found in the Red River Valley.

The borings already made show shales existing in the upper part of the strata penetrated, but as a general thing no water has been found in any of these bores in the shales.

The conclusions are that there does not exist in this section an artesian flow, unless it may be a very small one at shallow depths along the immediate base of the *coteaux*. Such a condition has formed springs which now break out in limited number.

THE TIFFANY UNDERFLOW BASIN, NORTH DAKOTA.

On the table-lands lying between the James and Cheyenne rivers, about 20 miles east of Devils Lake, in North Dakota, there is a small area of flat country where there appears to be a deep deposit of sand, which is charged with water that lies so near the surface as to make it practicable to use it for irrigation. While it might not be practicable at the present time in North Dakota to lift water by wind or horse power for general farming purposes, yet every farmer in this basin can, with comparatively little cost, obtain a sufficient amount of water to make sure against drought and to raise a sufficient amount of garden vegetables and the like for the family. If there is a market for the products of vegetable gardens there is no doubt that small farming by irrigation will pay even in that locality.

Assistant Engineer Follett examined this basin and makes the following note of it:

> In the neighborhood of Tiffany, Eddy County, N. Dak., is a level basin, some 10 or 12 miles square, which is underlaid at little depth by water. The soil is a sandy loam, underlaid by a thin clay subsoil. The latter is not over a foot thick; under it is fine, loose, clean sand; some 4 or 5 feet down in the sand water is found. No one has yet been through the water-bearing sand, as the water runs in so fast as to prevent digging. It is said that the sand gets a little coarser as depth is gained. This water is from 7 to 12 feet below the surface, the variation being due to differences in surface elevation. This water does not come from the Cheyenne or the James, at least not directly, as the flats are higher than either of these rivers. It is probably supplied by local rainfall, the gathering ground being to the west. At the east end of the flats is an alkaline lake in which may be the outcropping of this water.
>
> The land in these flats is not favorable for irrigation, as it has no uniform slope and is cut up by depressions. But wells could be put on the high points and enough land would be under each to use the full supply of the well. The water would have to be pumped either by wind or horse power. It seems to me that the best way to lift this water (the total lift being not over 15 feet) would be with some form of elevator pump operated by horse power. This kind of pump is simple in construction and maintenance and the farmers all have plenty of horses. A small reservoir (say of 1-acre area and 3 or 4 feet capacity) could be built, and the pump kept running at all times, and the water used whenever needed. Much could also be done by windmills, but it is not safe to trust to wind alone, as it might fail just at the time water was most needed. Both horse power and wind could be used to advantage on the same well.
>
> From a single well and large windmill, say a 12-foot Aermotor, or a 16-foot Enterprise, it is likely that 10 or 15 acres could be irrigated; with horse power, probably [illegible] acres.
>
> The supply of this water is supposed by the residents of the basin to be inexhaustible, as is always the local supposition in regard to "sheet water." But there is a possibility that large and constant use of it would very materially lower its level and possibly so exhaust the supply as to make it difficult to obtain the needed water. This is only a possibility and should not deter efforts to utilize the water known to be there now.
>
> The soil of the basin is fertile and sandy, and appears to be a good soil for alfalfa. Capt. C. H. Culver, 1 mile north of Tiffany, has 3 or 4 acres three years old, but it is not a good stand, and looks as if it needed more water than it has had this year. Large crops of cereals are raised whenever the rainfall is sufficient.

DEVILS LAKE AND ITS CONNECTION WITH THE CHEYENNE RIVER.

Devils Lake forms a part of the boundary line between Ramsey and Benson counties in North Dakota. The lake is about 35 miles long and 6 to 8 miles wide in the widest places. It is very irregular in its outline, the present shore line covering about 225 miles. The water of the lake is quite salty and contains considerable magnesia, and is unfit for drinking purposes.

The surface of the lake was, at no very remote period, at least 35 feet above the present surface, as is distinctly shown by the beach lines on the north side. Nearly one-half of the subsidence has occurred within the memory of men now living.

There are distinct evidences that the outlet was at one time into the Cheyenne River, as it would be to-day if the waters of the lake were 25 feet above its present stage. What has caused the subsidence is very difficult to determine, but the most reasonable explanation is the changing of the climatic conditions of the country. It is quite probable that the loss occasioned by evaporation and percolation of the water into the soil so nearly balance the rainfall on its surface and the small drainage into it from surface and underflow waters that a slight change in the annual precipitation or in the rate of evaporation is sufficient to account for the "ups and downs" of the surface.

Assistant Engineer W. W. Follett was instructed to examine the country lying between the south shore of the lake and the Cheyenne River, and makes the following notes and conclusions:

Referring to the maps (see Appendix 17) it will be observed that—

The lake shore is very irregular in outline and the course of Cheyenne River is tortuous. From Fort Totten south it is about 8 miles to the river, and this is the nearest the two come together.

Heading about 2 miles south of Fort Totten is a long draw running southeast. The upper end of the draw is dry, but it soon becomes marshy, then full of springs, and finally has a running stream delivering some 2 or 3 cubic feet per second into the Cheyenne. The first running water is about 3 miles from the lake. This draw is typical of many draining into the Cheyenne from the north.

At first sight it seems evident to one that this water must come from Devils Lake, as the river at the mouth of the draw is some 50 or 60 feet lower than the lake.

The south shore of the lake shows a line of springs from 18 to 30 or 35 feet above the present water level. These springs, so people familiar with the country say, extend along the whole south shore of the lake, but not along the north or west shore, and the whole country between Devils Lake and the Cheyenne River is underlaid by this water-bearing stratum. It is a fine sand not very strongly charged with water, the springs taking the form of bogs rather than running streams. It is from this stratum that these draws obtain their water.

Inquiry of the old residents around Fort Totten elicits the fact that the surface of the lake is about 13 feet lower than it was in 1867. My hand level showed the present surface to be about 15 feet below the highest beach line, which can be plainly traced. There are in places dim marks of others still higher up. This fall has not been constant. In 1882 the lake rose 2 feet, and this year has risen already over 1 foot (no record is kept at Fort Totten) and is still rising. The average fall for the past twenty-five years has, however, been about 6 inches per year. The cause of this subsidence is not plain. It is not fair to say that it is due to a decrease of rainfall, because other causes may be potent enough to produce the fall. There may be some subterranean outlet. There is a legend among the Indians that some forty or fifty years ago, what is now Stump Lake, about 10 miles east of the east end of Devils Lake was a forest, and was used by them as a winter camp, but that one fall when they went there they found it a lake so deep as to cover the tops of the tallest trees. It is supposed that this water comes from Devils Lake. I have not visited the place, so know nothing of the relative level of the two lakes. Even if it does come from Devils Lake it of itself would not account for one-twentieth of the fall, but it would show the possibility of there being underground outlets to the lake. It may be that the fall is caused by decreased rain or snow fall or increased evaporation, or both, but it does not seem to me that we have enough information about the matter to form any such conclusion.

About 7 miles west of Fort Totten there is a chain of small lakes extending some 4 miles south from the main lake. It appears from a hasty examination that the water level in these lakes and in the main lake are the same. All show the successive beach lines left by the gradually receding waters and the land between them is a porous sandy, or gravelly soil, through which water would percolate freely. The land between the lakes is in no place more than 20 or 25 feet above the present water level.

Extending southwest from the most southerly lake is a long wide draw. The highest point in this draw, as near as I could locate it with a hand level, is only about 1,500 feet south of the last lake, about 30 feet above its waters, and is a bed of bowlders much water worn and packed together. The first 2 miles of this draw are dry. It then becomes very marshy, but no running water is seen, probably because the draw has so little fall, this being so slight as scarcely to be detected with the hand level. The last 2 miles before it reaches the Cheyenne it falls rapidly and carries some water.

There is no doubt in my mind that this once formed an outlet for Devils Lake, through which its waters reached the Cheyenne, and this at no remote period, perhaps not more than fifty or sixty years ago. It may be that the water flowed here until its influx into Stump Lake.

Cheyenne River is a perennial plains stream. It is now carrying at a point due south of Fort Totten about 60 cubic feet per second. Much of this is rain water, but it carries at all seasons a good stream, which is supplied by springs coming from the sand stratum before mentioned. Its bed is below the level of Devils Lake to the north and the James River to the south, the latter being merely a storm-water channel. Its local drainage is small, almost nothing from the south and but little from the north.

There is in this river enough water to do considerable irrigation, but, as in all of the rivers in this region, the fall is so slight that the water can not be taken out onto the land by gravity, and the only crop raised, wheat, will not warrant the expense necessary to pump the water. The lift would have to be from 30 or 40 to 100 feet or more, as the valley is rather narrow and rises rapidly away from the river.

In some of the draws coming into the river is considerable level land, but it is all or nearly all wet from springs and does not need irrigation.

My knowledge of the country to the west of the lake is not sufficient for me to give with any certainty the origin of this water, but I know that there is a high stretch of country some 30 miles wide north and south, and from 75 to 100 miles long, east and west, between the Mouse and Cheyenne rivers, which may be, and probably is, its gathering ground.

THE UNDERFLOW FROM TURTLE MOUNTAINS.

The Turtle Mountains (I will call them mountains out of respect to the people of the Dakotas, who have little else that suggests such a name) are in the extreme northern part of North Dakota. The boundary line between the United States and Canada passes through the northern portion, leaving about one-fourth of them in Canada. The area embraced is about 724 square miles, 166 square miles being in Canada and 558 in North Dakota. They are oblong in shape, being longest northwest and southeast, and are about 120 miles in circumference, and surrounded by an open plains country.

There are five or six counties in North Dakota, to the southeast, which are supposed by some to receive their supply of subterranean water from these mountains, and many think the water of Devils Lake comes from this source. It was for the purpose of examining this supposed source of subterranean water supply that I spent nearly a week in driving in the interior and almost encircling their entire base, omitting only about 30 miles of the northeast portion which lies in Canada. I had for a companion, interpreter, and driver a gentleman who is a surveyor, and quite well acquainted with the country, and from him and the Indians on and about the reservation I obtained considerable important information.

Topographically considered these mountains resemble the Coteaux of the Missouri. They are about the same elevation above the sea as the Coteaux, which lie to the south and west, but not as high as those on the western side. The mountains have the same undulating surface, with gently sloping hills, with small valleys scattered here and there over the whole interior. The general character of the soil and the material forming the mass is the same as in the Coteaux, it being glacial drift with but few bowlders, and with but little solid rock to speak of. Unlike the Coteaux nearly the whole surface is covered with timber, aspen, oak, and some other varieties, but no pine. Scattered over their surface are perhaps 100 small lakes, which lie in the lowest valleys. In the valleys lying a little higher are marshes with more water and in wet seasons these marshes are entirely submerged. The more elevated valleys, and those which receive but little surface or underground drainage, are covered with a heavy growth of grass, making fine meadows, from which thousands of tons of hay are annually cut. Nearly all of these lakes, marshes, and meadows are landlocked, having no outlet. The soil has the capacity to absorb water freely, and in the interior there are no recent water-worn channels. Probably a larger percentage of the water that falls on these mountains is taken up by the soil than on the Coteaux. I am informed the lakes in the mountains are not so readily affected by wet and dry seasons as they are on the Coteaux.

The timber which covers the mountains at the present time is mainly of a recent growth. The Indians say about sixty-five years ago it was nearly all destroyed by fire and wind. The age of the timber and the character of the undergrowth seem to corroborate this statement. In such places as are protected by lakes and marshes there are some larger and much older timber. One of the county commissioners of Rolette County reports that he has cut timber on these protected places that was 2½ feet in diameter, which must have been at least 400 years old. The Indians also report that the timber that was destroyed sixty-five years ago was not as large as the present growth. This indicates that the forests have been at least twice destroyed by fire.

It is the general opinion that more rain and snow falls on these mountains than on the plains, but from the testimony of those who live in the mountains and those living just outside I judge the difference in the annual rainfall is very little. The effect of the forests on the climate within these mountains is very marked. The timber and undergrowth shade the ground and break the force of the winds. The snows of winter are not blown from the surface, but lie on the ground much later in the spring and melt so gradually that the water is absorbed by the soil, instead of running off rapidly, as it does on the plains. The climatic conditions of even so small an area as this are so changed that farming is successfully carried on here even in seasons where crops are a failure on the adjoining plains for a lack of sufficient moisture. A large percentage of the rainfall is either retained in the soil or collected in the lakes and marshes. The loss by evaporation is greatly impeded by the forest protection.

With the exception of Willow and Oak creeks there are no water courses that extend but a short distance into the interior of the mountains. The head of Oak Creek is in a chain of lakes which extend back into the interior nearly to the boundary line. During the last few years the surface of this chain of lakes has fallen below the outlet of the creek, and in August the surface was fully 3 feet below. I am informed that the situation at Willow Creek is about the same. There are about fifteen other drainage channels on the American side that simply drain the outer rim. Nearly all of these carry a little water through the whole year. In August about ten were carrying from 10 to 60 gallons per minute, and others from 1¼ to 7 cubic feet per second. Probably not exceeding 17 cubic feet in all were escaping from the mountains on the surface, and all of this water soon disappears on the plains, none of it reaching permanent surface streams except in times of high water.

The Mouse River encircles the Turtle Mountains on the southwest and north sides, towards which river the surface drainage of three-fourths of the country around about trends. A small area on the easterly side is drained by indistinct water channels, or coolies, leading towards Devils Lake; the remaining drainage is towards the Pembina River. If the direction of the subterranean flow follows the surface drainage, not over 5 or 8 per cent of the ground drainage from these mountains is available for the country lying to the southeast.

The conclusions concerning the Turtle Mountains, as being a gathering ground for an underground water supply, are, that while these mountains probably receive but little more rainfall than the surrounding country, they are capable of, and contribute more water to the underground supply than the same area of plains country, mainly because of the protection afforded by the timber and the small amount of the precipitation that falls on them being carried away by surface water courses. Unless the uppermost strata of impervious material which underlies that country dips in an opposite direction to the surface drainage (which is not very common) the direction of the greater part of the underflow is to the south and west into the valley of the Mouse River. Possibly one tenth of it may take a southeasterly direction towards Devils Lake.

There are some reasons for suspecting that Devils Lake and the country in that vicinity may be supplied from the underflow from the Mouse River. The elevation of this river will admit of this. It will be seen by referring to the map that the Mouse River enters the United States from the northwest, crossing the boundary about 60 miles west of the Turtle Mountains, and extends into North Dakota nearly 100 miles, when it turns in an opposite direction, forming a bend like an elongated mule shoe. This bend is a very low divide, and it is thought by many that the river at one time flowed on in a southeasterly direction to the Devils Lake country. There are evidences of this theory found underground in the country east of this bend in the river where wells have been dug which penetrate a deposit resembling that of an old river bed. In these wells have been found driftwood and other débris which usually marks the margin of a river. These evidences lie 8 or 10 miles easterly of the present bed of the river. The discussion of this question, however, belongs more to the geological branch of the investigation.

ST. MARYS RIVER, NORTHEAST MONTANA—ITS DIVERSION FROM CANADIAN TERRITORY.

An examination was made in September of St. Marys lakes and river with a view to ascertaining if it is possible as well as practicable to divert the flow of this river before it reaches the boundary line, and to lead it out for irrigation purposes by a canal that would be wholly within the United States. The accompanying sketch map (Appendices 15 and 16) shows approximately the location of the lake, river, and the line which the proposed canal would traverse in reaching the Milk River drainage. The examination of the line was simply a reconnaissance of the country on horseback with only a hand level and an aneroid barometer to determine levels and elevations.

The St. Marys River is the outlet of the lower of two lakes of the same

same. Its course is northeasterly, and in about 9 miles it crosses the boundary line into Canada. The river is reinforced on its western side by Swift Current, Kennedy, and one or two minor streams. Swift Current is the main tributary. Its source is in the mountains, and it is the drainage channel of a large area of elevated country extending back to the continental divide. The St. Marys lakes are supplied from springs, and underflow, and mountain streams, which furnish a permanent supply of water. From the outlet to the boundary line the channel of the St. Marys River is through a narrow valley, having a grade of 60 feet to the mile. The discharge from the lower lake in September was 520 cubic feet per second. This is its minimum flow. From high-water marks along the bank it is estimated that the average maximum flow is not less than about 3,000 cubic feet per second. The discharge of Current Creek at the same date was 325 cubic feet per second. This is also the minimum flow of this stream. From the two streams we have 850 cubic feet per second, as the minimum amount of water that can be diverted for irrigation purposes.

The general plan for the canal and its location is about on the following lines: To build a low diverting dam across the outlet of the lake, take the water out on the west side, and follow down that side through a meadow and cross the stream with a flume. This is done to avoid a mile or more of very heavy rockwork if the canal is taken out on the eastern side.

After crossing over the river to the east side the line follows down valley about 3½ miles; then it turns out of the river valley and follows along the south side of a broad ravine for about 4 miles; then it skirts along the foot of a hill on the south side of a small valley until it reaches a deep depression or ravine, which has cut down into the narrow divide between the St. Marys and Milk rivers; then following up this ravine 1½ miles it reaches the summit of the divide. At this point the water can either be turned down in the North Branch of Milk River or it may be keep up on grade and carried along on the right bank of the North Branch. If turned into the Milk River channel it will cross the boundary line into Canada. If it is kept up on grade from the summit it is quite probable that it will get out of the valley of the North Branch and can be turned southeasterly before it reaches the boundary. This question was not fully determined, for lack of time and proper leveling instruments. If the water is allowed to flow down the North Branch it would have to run over 100 miles in Canada before it would again get back into the United States. If it were kept out of the channel on the North Branch and could be taken from that valley into the valley of the South Branch, it could then, without doubt, be kept on the country between the Marias and Milk rivers, and finally be made to serve the lands wholly within the State of Montana. The estimated length of the canal to the divide is 18 miles. It is proposed to reinforce the canal in times of low water in the St. Marys River by turning a part of Swift Current River into the canal at a point just above where it is carried over the river in the flume. If an attempt is made to divert all of the waters of the St. Marys River, the canal should have a carrying capacity of not less than 1,200 cubic feet per second. I am of the opinion that it is possible to turn the water into the North Branch of Milk River, but whether it could be carried on beyond that divide can only be determined by a survey. I am also of the opinion that it will require a close survey for the purpose of making an estimate of the enterprise before it can be pronounced a practicable one.

The diversion of so large an amount of water from the St. Marys

River would in some seasons of the year exhaust the river at the head works, and for a mile or so below it there would be a constantly running stream passing the boundary line. It will be observed by referring to a sketch map, Appendix No. 14, and the maps of Montana, that the water supply of the St. Marys lakes and the river south of the boundary line has its origin wholly within the United States; that is, no part of the river in the United States receives water draining off the Canadian soil; and the diversion of this water for beneficial uses in Montana rightfully belongs to that State, especially so long as it is unappropriated by the Canadians.

It is safe to place the average volume of the river at 1,200 cubic feet per second. A fair average value of a cubic foot of water per second in perpetuity is not less than $1,000 to the land belonging to the farmer. The duty of a cubic foot of water per second will be about 150 acres, therefore we have a capacity to reclaim 180,000 acres of land by the proposed canal. The increased value of the land thus reclaimed would be at a conservative estimate $10 per acre, or amounting to $1,800,000.

I think I am safe in saying that sufficient water is in the St. Marys River, and I am creditably informed that there is plenty of fine irrigable land awaiting only the touch of water to make it produce magnificent crops.

ARTESIAN WELLS, IRRIGATION AND EXPERIMENTAL WORK.

At the beginning of the investigations of the artesian-well problems in the summer of 1890, we found the people in the Dakotas generally quite ignorant of the methods irrigation. Some doubted the policy of agitating the question of the necessity for irrigation and the utilization of the artesian supply, believing it would be a detriment to the future prosperity of the country to have the world know that irrigation was at all necessary for successful farming operations; others believed that artesian water would "kill and not cure," and there were plenty of instances cited to us of the proof of this. Some thought that a dry and thirsty soil would take in the water to such an extent that the flow from a well would serve only a few acres at best. Others thought the country so level that water could not be made to flow but a short distance; and others believed that the expense of irrigation from artesian wells would be too great for profitable farming. In fact, the people were generally at a standstill, halting for want of definite knowledge of the practicability of irrigation and how to utilize the water. At this time there were scores of artesian wells in South Dakota, the water from which was running to waste and flooding the very fields in which crops were drying up for lack of moisture. It was this condition of affairs that led to the suggestion that a few weeks could be profitably devoted to devising and directing some experimental irrigation work in the Dakotas.

The plan at first was to establish two or three experimental stations at accessible points where artesian water could be had, on a farm where the owner would do all the necessary work of constructing reservoirs and ditches, and also to carry on the farming and irrigation operations under our directions, but this plan had to be changed somewhat on account of the lateness of the season when the order was finally given to proceed. The services of Mr. B. S. La Grange, a practical irrigator of twenty years' experience in Colorado, were secured. He reached South Dakota about the 10th of May last. At that time seeding was nearly over.

On account of the copious rains that had already fallen the ground was in better condition than it had been for several years, and the general opinion was that irrigation would be unnecessary. The greatest fear was that the hot dry winds that had occurred in previous years during the months of June and July might shorten the crop, but on the whole there was a general feeling of hope in the feeling of security which the favorable spring weather promises, so that many who the fall before had partially planned to make a trial of irrigation were induced by the favorable outlook to postpone it on account of the cost of the necessary appliances, and also on account of the uncertainty of the practical outcome of the experiment. The result was that comparatively few attempts were made this season to farm by irrigation.

The most prominent attempts of this kind were made in Brown, Spink, and Beadle counties in South Dakota, where a half a dozen wells had been put down during the fall and spring especially for irrigation purposes. The water furnished by these wells was used during the fall and winter for wetting the land in the nighborhood of the wells, which was done without taking much pains with its distribution. Consequently much of the land was excessively irrigated, there being instances where some of the land was covered with ice 3 feet thick, while in the same neighborhood some of it was not wet at all.

Mr. La Grange was instructed to visit three or four farms where the owners were intending to utilize the waters of their artesian wells during the summer for farming purposes and to select from these two places where the plan of the distribution of water and its application to growing crops could be made object lessons in irrigation for the benefit of the public. One selection was made in Beadle County, 8 miles north of Huron; the other in Brown County, 1½ miles east of Aberdeen. Both of these farms are supplied by wells having a flow of about a cubic foot per second, or 450 gallons per minute. The flow being so small it was found to be impossible to make much progress in flowing the water over the land, besides it being a great waste of water which could not be prevented in attempting to flood it with so small a head of water.

To overcome this difficulty storage reservoirs were built at both of these places, one having a holding capacity of 35 acre feet, the other 15 acre feet. These reservoirs were in every respect a success.

The well and farm at the station 8 miles north of Huron is managed by Mr. R. O. Richards, who employed an experienced irrigator as one of his farm hands, and by the aid of his experience and the direction and advice of Mr. La Grange is able to irrigate 300 acres in a very creditable manner. Had the storage reservoir been built at the time the well was completed (last fall) at least 400 acres additional could have been irrigated. The experiments on the Richards farm have demonstrated that the amount of land that can be irrigated in the Dakotas with so small a flow of water, by the aid of storage reservoirs, has greatly exceeded our first estimates.

The irrigation done during the fall and winter on this farm, as well as on the one at Aberdeen, proves that it is entirely practicable to irrigate in the fall and winter season. On account of the peculiarity of the Dakota soil it retains the moisture that is applied in fall and winter, so that one light irrigation at the proper time during the summer will suffice to carry the crop through in good condition to maturity.

The storage of the constant flow from an artesian well enables the irrigator to utilize the accumulated water in large quantities for a few hours, this being a great saving in time, as well as greatly increasing the duty of water.

Mr. Richards estimates that his land, including well, reservoir, ditches, etc., cost $15 per acre; also that every acre of thoroughly irrigated wheat, if sold at 75 cents per bushel, yielded an income this year of $30 per acre, or double the original cost of the land and improvements.

The following is his report of the method of irrigation, kind of crops raised, etc.:

The irrigated wheat was planted on old land, which had been plowed in the fall of 1890 to a depth of 6 inches. This land was flooded during the months of November and December, 1890, and January, 1891, and was partly irrigated in the first part of June, 1891, as nearly as the capacity of the well would allow, the reservoir not being constructed in time to do thorough work. The seed was Scotch Fife, sowed broadcast 1½ bushels to the acre, early in April. It was cut with binder the last of July. The best irrigated wheat measured (cut, stacked, and thrashed before witnesses) 53 bushels and 20 pounds to the acre of hard wheat. While the average yield of full fields can not be determined definitely, owing to its being cut and stacked together with spots not irrigated in the same field, the average yield of the whole tract would, however, exceed the nonirrigated in that locality by from 15 to 25 bushels to the acre.

The oats land was plowed in the fall of 1890 6 inches deep. Sowed broadcast May 1 at the rate of 2 bushels per acre of the white Russian variety. The straw was of unusual length, some parts of the field averaging nearly 6 feet. The land was flooded during the preceding winter, and no irrigating was done during the growing season. Average yield was 80 bushels, while a few acres yielded 100 and more.

Work in barley was same as in oats. Sown 1½ bushels to the acre. Yield, 55 bushels to the acre. Land not irrigated during growing season, but flooded during preceding winter.

Millet was sown broadcast one-half bushel to the acre latter part of July. Variety, broom-corn millet. Yield of hay, 3 tons to the acre.

Yellow Dent corn was planted on ground plowed May 1 and planted immediately thereafter. Land was wheat stubble. Partly irrigated the first of July, and it yielded 40 bushels of good sound corn to the acre. The frost the latter part of August injured a part of the field where it was not irrigated and ground was dry, but where it was moist it did no perceptible harm.

Irrigated flax was sown on breaking about May 15 at the rate of three pecks to the acre. Land was not flooded in the winter, but was irrigated once during the latter part of June, and yielded from 16 to 20 bushels to the acre, according to location and treatment, while unirrigated flax in the same fields sown June 10 yielded but from 3 to 4 bushels to the acre.

The potatoes have not been harvested, but the hills run from eight to twelve or more good big potatoes to the hill, promising an immense yield. They were planted the first of June, cultivated like corn, and irrigated but once, the latter part of June.

One acre of alfalfa was sown on same land with wheat, and since cutting the wheat and irrigating the land the alfalfa is making a fine showing, experienced irrigation farmers declaring that alfalfa growing under irrigation will be a success.

The other experimental farm where Mr. La Grange devoted considerable time in planning distributing ditches and superintended the irrigation is owned by Mr. H. C. Beard, of Aberdeen. The well on this place was completed in the fall of 1890, and considerable land was irrigated that fall and winter. The crops on this farm were put in very late. Some of the land was so excessively irrigated, it was not until the middle of May that it became dry enough to plow, and the season being so far advanced a large part of the crop was put in without plowing the land. The wheat was sown on ground that had not been plowed for two years and the only cultivation it had was by a disk harrow run over once to cover the seed.

The land that was so heavily irrigated in the winter and put into crop in this crude way made a very good crop without any other irrigation, while that in the immediate vicinity that was not wet in the winter or irrigated at all during the summer was not worth the cutting.

A storage reservoir holding 15 acre-feet was built to hold the flow of this well which admirably served the purpose and made it possible to at least double the effective value of the well. No detailed reports of the yield of the crops on this farm have been received, as the grain was not threshed at the time of latest advice.

Mr. Beard estimates at the time the crops were harvested that the increased yield of the grain that was properly put in and irrigated would be 20 bushels per acre for wheat. He further estimates the value of the increased yield due to the irrigation will be sufficient this year to pay the cost of the reservoir, ditches, and half of the expense of the well.

In addition to the time Mr. La Grange devoted to planning and giving instructions in irrigation at these two stations he visited other localities both in North and South Dakota where other farmers were making their first attempts at farming by irrigation, and giving them counsel and advice, which is estimated to be of great value. Since the close of the field work, letters of inquiry have been sent to those who have been experimenting or have been farming by irrigation during the past season. Without exception the replies all show large increased yields over nonirrigated crops, even this season, which has been (with the exception of two or three counties in South Dakota) one of the best years known in the Dakotas.

Mr. J. W. Barker, near Mellette, South Dakota, utilized a part of the water from his well this year. He says:

> Experience is the thing we need most now. Not knowing anything about irrigation it was an experimental season with me. I threshed none of my irrigated grain separately but as nearly as I can estimate I will have about 600 bushels ahead of what I would have had without irrigation.*

Mr. J. P. Day, of Mellette, president of the board of trustees, South Dakota Agricultural College, writes, November 26, 1891:

> My report for the season of 1891 must be very meager, as my well was not finished till the 20th of April last. There was no time to wet the soil before the seed was sown. Owing to the widespread belief that to flood the land before the seed made some growth would be to bake the soil and prevent its ever coming up, the land was not irrigated till the crop had attained a desired growth, which, owing to the prevailing drought, was not till June.
>
> Experience has taught me that I can irrigate with artesian water whenever the crops want it. The crops that were irrigated even at that late date (and received but one wetting) yielded immensely as compared with those not irrigated. Wheat made 24¼ bushels one variety and 29¼ bushels another variety to the acre, while that not irrigated and in the same soil, only separated by a public road, made but six bushels per acre.
>
> There was even a greater difference in barley and flax, while millet, vegetables, and especially an acre of young forest and fruit trees made a most satisfactory showing.
>
> I sowed 10 acres of winter wheat in October last and flooded it as soon as sown and saw no injurious effects, though a month's late sowing; it promises well, came up strong, and grew well till freezing weather.
>
> The experience of the last four or five years goes to show that farming without irrigation, in our part of the State especially, is too unreliable to be followed up, and if the best soil in the world is to be made valuable and yield up its treasures to bless the husbandman and feed the hungry it will be necessary to have at command a supply of water to feed plant life just as it is wanted. I am satisfied that we have never had, one year with another, sufficient rainfall to bring out the full possibilities of this splendid soil, and, when a general system of irrigation is adopted and large farms are divided up as they must be, the irrigated regions will enter upon an era of prosperity that can never be attained by those parts of the country that are subject to alternate drought or destructive flood.

---

*Eighty acres in wheat.

I am in hopes that I will be able to make a good strong showing next year, as preparation and experience will both be prime factors in its operations.

Mr. J. M. Miles, of Redfield, S. Dak., makes the following statement to The Dakota Farmer concerning his experience in gardening by irrigation:

I am running a market garden in the suburbs of Redfield. My place has been used as a garden ten years. All the crops used to be magnificent, but they gradually failed, owing to drought, till in 1888 and 1889 they were almost a total failure. Everything seemed to suffer, especially the crops that matured late in the season.

Cabbages did not head at all or made only little dried-up heads. The worms and lice nearly devoured them.

Onions grew about as well as anything, but made a very poor yield.

Tomato vines grew small and sickly looking, with a few little, half-dried tomatoes, and four-fifths of them had a black rotten spot on them which gradually destroyed the whole fruit before it was ripe.

Cucumbers and squashes did not mature any desirable fruit and but little of any kind. The squashes fell off the vines when only an inch or two in diameter. Nothing in the garden was of either good quality or yield. It did not require remarkable business foresight to see that such farming would not pay. I figured with windmill companies on the cost of mills and pumps to raise water, as I had the creek nearly around my place and had only to raise the water about 30 feet to the highest point of my land, and then figured the expense of laying a pipe from the artesian well in this city. I had to carry the water 3,180 feet. I found I could put down an inch pipe for about the same sum I could put up a mill, tank, and pump, and the pipe would flow summer and winter, wind or no wind, and the water would always be warm. My pipe flows 720 barrels a day; this seems like an enormous amount of water, but it is not enough to thoroughly irrigate over five acres, if it will so much. I got the pipe down about the middle of May, 1890. I knew nothing of irrigation. I first tried flooding the land by storing up a head ditch full and letting it out with a rush. My crop was all sowed and most of it up. I soon abandoned flooding, as I found that where the water stood for any length of time and the ground was not covered with foliage of the crop it baked a crust around the plants or over the seed, and more harm than good was done. Then I tried sprinkling the ground after the sun was low or early in the morning. This was not practical. I then tried running the water along the rows a few inches from the plants. This seemed to be about the most feasible and I followed it up and have ever since. I run the water down little furrows made with a hoe and set all my plants in the furrows, then run the water down on them a few minutes every day for a few days, and then fill up the ditch and make one a few inches away. Then irrigate as I think they need it. In this way I transplant all kinds of plants in the hottest weather and all day and never lose any to amount to anything. I tried to cover too much ground at first, but found I must save some of my crop and let the rest take its chances. I confined my efforts to tomatoes, cucumbers, squashes, and cabbages. I set my tomato plants 4 feet apart each way and several weeks before frost there was not a foot of the ground that was not covered. The vines underneath were loaded with a great smooth fruit, many tomatoes weighing over a pound apiece. Not one in a hundred had a blemish where the water hit them as it should. There were in the field some little ridges and knolls that I could not reach without more work than I had time to give them, and they got little or no good of the water. On every one of these places the vines and fruit were exactly like those of the previous two years. Cucumber vines irrigated kept me busy every day picking nice fruit, while some not reached gave a few wilted cucumbers and then turned yellow and died. The first squashes all fell off, as I did not think they needed the water and was using it elsewhere. When I saw how they did I turned the water on them and then every one stayed on and grew till frost killed them, but were too late to mature. I let the cabbages go till the tomatoes and vines were killed by frost and then gave them attention. This did not give them a good chance, as they had needed water for some time, and though still alive they had not grown as they should have done. They began immediately to grow and made big heads, but not as ripe as they should have been. In this field, too, there were some little places not reached by the water. There the cabbages either were devoured by lice and worms or dried up, and failed to make any heads at all. When the frost struck my vines I had the water running on just as many rows as possible, and every row so watered did not freeze or but very little, and kept on bearing for nearly three weeks more. Those that were dry were killed the 30th day of August. This year's experience is only a repetition of last year's except that I began earlier to irrigate, or rather kept it up all winter, and could reach more ground than last year. I had a good share of my land covered with ice from a foot to 3 feet deep. All land covered in this way gets along with much less water than the rest. Fruit, currants, gooseberries, raspberries, cherries, plums, and apples have done finely this year and never did before.

At first I was afraid of the artesian water, as I had heard so much about its making "gumbo," baking the ground, killing things, etc. But I have used it on every kind of garden crop, and my wife has used it freely and continually on all kinds of house plants, and with only the best of results. It may be possible to get the ground too wet, but I think I have not been able to do so, as the ground having the most water has given the best results every time. I had so little water I could not experiment for the sake of seeing what I could do, but so far as I have tried it I am satisfied that irrigation in a sensible, practical way, with plenty of water, is far ahead of the most favorable rains. I don't know as my way is best or even as good as some other way, but it is way, way ahead of seeing a crop fail.

Mr. Miles states that he sold 500 bushels of tomatoes raised on 1 acre of ground by irrigation. None of the tomatoes were sold for less than $1 per bushel. They were pronounced superior to any ever seen in the Dakotas, native or imported. Mr. Miles uses this small flow of water direct from the pipe. With a reservoir holding a two or three days' supply, he would undoubtedly be able to double the area irrigated and could handle the water much more satisfactorily.

TABULATION OF ARTESIAN WELLS DATA.

The report of Mr. B. S. La Grange is submitted. In it he gives some practical and valuable suggestions concerning methods of irrigation in the Dakotas and makes comparison of some of the irrigation problems in that country with those in Colorado.

GREELEY, COLO., *December* —, 1891.

SIR: Receiving a commission on May 7 from the Department of Agriculture as irrigation expert, I immediately started for the points designated in the Dakotas. During the time I was in South Dakota I visited the principal points where artesian wells were located, among others, Huron, Aberdeen, Redfield, Mellette, Woonsocket, Ellendale, and Mandan, and showed those interested how they could take advantage of the artesian supply for irrigation to the advantage of themselves and of the commonwealth.

At several places I assisted in establishing object lessons showing practically the possibilities of irrigation and the increased value and products arising therefrom.

The country, though undulating, as a whole is very level, with a fall of only 2 inches per mile, so that the method of carrying water in ditches for any great distance, as in Colorado and other Western States, is not applicable. But with the supply furnished by artesian wells it is not necessary to carry the water any great distance, and there is no difficulty in obtaining sufficient head, even on level ground, to carry water to any point desired.

While the principles to be followed in irrigation are necessarily the same as in any country where irrigation is practiced, the character of the supply and the configuration of the country necessarily lead to a different system of distribution. Where water is obtained from the mountain streams, as in Colorado, the supply is variable. The streams are high only for a few months in the spring and early summer; consequently the supply is limited in the latter part of the summer, and the farmer is to some extent limited in his choice of crops to those which mature early in the season. With the artesian wells, on the contrary, the flow is constant throughout the year. Hence, to fully utilize all the water it is necessary to consider such ways as will make it possible to use the water throughout as much of the year as possible, and to save it when not being used.

In Colorado the flow of a cubic foot per second throughout the irrigating season is sufficient for about 100 acres. But with the constant flow from the artesian well the duty of water in experienced hands will be much greater—it is safe to say 200 acres per second foot.

The method which I would use, were I farming in Dakota, would be to put the well and a reservoir on the highest elevation of the farm wherever practicable. This reservoir should be of a size sufficient to hold the discharge of the well for from three days to two weeks, according to circumstances. This could be made when work was not pressing, without hiring other labor than that already on the farm, and the cash outlay would be inconsiderable. In order to lay out the system of ditches, especially if the ground does not have a uniform slope, it would be best to have a careful map made showing the elevations, and establish the system of ditches according to the circumstances. Several main ditches should be run from the reservoir, each one having a gate in the reservoir embankment, which could be closed when desired. The ditches leading from the reservoir should not be excavated, but built on top of the ground by throwing up embankments on either side, say 2 or 3 feet high. Some structures might be necessary in the ditch to check the water at any desired point and force it out of the lateral outlets. These outlets should be made permanent by making a small wooden gate, or an opening could be made in the bank at any point desired, and closed when desired. By these means, and by raising the water in the reservoir above the ditch and closing the check, sufficient head can be obtained to carry the water wherever desired. The lateral ditches which would be made by the double mold board plow would be temporary. Small checks or dams could be made in these, as necessary, by throwing up the soil from the bottom of the ditch itself. In general, these should be not more than 20 rods apart.

As an illustration of the methods thought applicable to Dakota I will mention one case, that on the farm of Mr. Beard, near Aberdeen, where a reservoir was built on ground somewhat higher than the well, covering about 3 acres, with 5 feet depth of water. The casing of the well was extended high enough so that by constructing a flume the water ran into the reservoir by its own gravity. The reservoir holds about five days' flow of the well. From the reservoir three main ditches lead the water, following the slope of the country. From these, laterals are taken out whenever it is necessary for a general distribution of the water.

By the aid of the reservoir and the system of distribution the accumulated flow of the well for days can be used to serve more land with less labor than by attempting to irrigate with the water flowing directly from the well.

This is a fairly typical example of what can be done in the James River Valley. There was no difficulty found in distributing the water which was not successfully overcome, so that with similar methods there is no more difficulty in irrigating that country than the plains of Colorado.

Having a continuous flow of water, the crops need not be confined to those which mature before the drought of summer. There should be a diversified agriculture, and crops should be selected which will need water at different periods. The water can then aid directly the growing crops throughout a greater portion of the season and thereby reach the highest duty.

But the use of the water need not be confined only to the growing season. Just as soon as the crops are out of the way irrigation and the plow should be started and kept up until frost stops operations. Even then, watering may be carried on by running the water on the ground, and stopping it when the ice has reached a thickness of from 6 to 12 inches. By these methods a large amount of land would become soaked up, and in most cases would have sufficient moisture to grow a crop of cereals without further irrigation.

In all irrigation much judgment and experience are called for, as well in knowing when to stop irrigation as when to begin. One of the secrets in this, as in growing live stock, is not to allow the crop to stop growing, but to apply the irrigation before it has reached the point where growth has stopped for the lack of moisture, for the crop very rarely recovers from such a stunting. Each irrigation when made should be thorough, and will be found to require more water than the inexperienced irrigator would suppose. In the climate and soil of Dakota one irrigation will generally be sufficient for the cereals. By the use of the reservoir irrigation can be carried on in the daytime only, during which time the best service can be obtained because of the better opportunity for knowing how operations are progressing. During the rainy weather, or when the crops do not require watering, the flow of the well may be stored until it is needed.

In many respects the irrigation from artesian wells has advantages over our system of taking water from the mountain streams, and is even cheaper. The water is practically constant in flow, so far as we yet know. In Colorado the cost to bring water to one's land varies from $3 to $15 per acre. In Dakota the constant flow will allow each cubic foot per second to supply 200 acres under good management. If a well flowing 6 cubic feet per second can be put down for $2,500, the cost per acre is less than it is with us, where we bring our water from the stream in ditches.

From what I have seen of the conditions of Dakota, I am firmly convinced that its possibilities of irrigation are great, provided the Commonwealth by a wise system of laws fully conserves its wonderful supply and assumes sufficient control to be assured that the public interest is not thrown away by private individuals. The damage which may occur through carelessness in sinking wells, in imperfect casing, in poor positions, in multiplying wells in a district after there are indications that the capacity of that district has been reached, is irreparable, and must be controlled by the State by the wisest legislation if it does not wish to see the loss of the vast possibilities of wealth in the artesian stratum beneath their feet.

Respectfully,

E. S. La Grange,
Irrigation Expert.

E. S. Nettleton,
Chief Engineer, U. S. Department of Agriculture.

ARTESIAN-WELLS LEGISLATION.

The people of South Dakota have generally become convinced within the last twelve months of the great benefits to be derived from irrigation, and of the practicability of utilizing the water from artesian wells for irrigation purposes. Last winter a law was enacted which enables the people of a township to bond themselves for the expense of putting down artesian wells. This law provides that water found in the artesian basin shall be the property of the public and dedicated to the people of the State, subject to appropriation. It provides that when 30 or more persons in a township owning at least 80 acres of land desire to bond themselves for putting down artesian wells, they may notify the State engineer to locate such wells, which shall not exceed nine 6-inch wells, or sixteen 4½-inch wells in any township.

It provides also that the State engineer shall, within twenty days from the date of said request, locate the desired number of wells and file his report with the register of deeds of the county, who is required to notify the chairman of the board of supervisors of the township.

The chairman is required within five days after receiving the notice to call an election for the purpose of voting on the question of sinking the proposed wells. The elections are to be conducted and votes canvassed in the same manner as in all township elections.

It provides that the board of supervisors shall, within three days after it shall be found that a majority favor bonding the township, advertise for bids for sinking said proposed wells or any of them.

If the contract with the party who bids is accepted it requires him to begin work within ten days and prosecute it continuously until the well is completed. The State engineer is required to examine the well after its completion, and if he finds the contract has been complied with he shall file his report and acceptance with the township supervisors, who shall attest to the same.

When bonds are issued they are a lien on the property in the township, and in case the township officers refuse or neglect to perform their duties, and a default is made in payment of principal or interest, the holder of the indebtedness may apply to the circuit court of the county, which shall enforce the payment.

Those desiring to use water for irrigation shall apply to the supervisors, stating the number of acres to be irrigated, and shall bid for the use of water, an acre foot being the unit. But the users of water shall not be required to pay exceeding 7 per cent pro rata of the amount of the bonds for sinking the well.

The townships have a lien upon all the land served by the water for all unpaid rentals. The township treasurer collects the water rents and pays the same over to the county treasurer, who places it to the fund out of which to pay the interest on the bonds. In case the water rentals are not sufficient to meet the interest the township officers are required to levy and collect a tax sufficient to cover the deficiency, but such tax must not in any one year exceed 3 per cent of the taxable property of the township.

Townships may put down artesian wells for public use, such as for filling lake beds, streams, and artificial reservoirs, providing that such wells, in the opinion of the State engineer, do not interfere with the flow of the other wells for domestic and irrigation purposes.

The better right to the use of artesian water is:

First. For domestic use, and the watering of trees, grass, shrubbery, etc., about the house, not exceeding one-half acre in extent.

Second. For irrigation and manufacturing, providing the use of it for manufacturing purposes does not diminish the flow or interfere with the flow of water for irrigation purposes.

The chairman of the board of supervisors has the care and supervision of the wells, and for such service is entitled to $50 per year.

Any person, or corporation, owning land may hereafter sink wells upon their own lands, and use the water for beneficial purposes, providing the use of such water does not interfere or diminish the flow from adjoining wells.

Under this law twenty-seven townships have made application to the State engineer for the location of artesian wells, and one hundred and fifteen wells have been located. Out of this number twenty-one townships have voted to bond themselves, and two have placed their bonds, and on October 1 sixteen wells have been sunk, or have been contracted for.

CLIMATIC CONDITIONS OF THE GREAT PLAINS.

From information gathered from the weather service records, from the people in the central and eastern parts of the Dakotas, and from those between the ninety-seventh meridian and one hundred and first in western Nebraska and Kansas, it appears that there is usually rainfall sufficient in the whole year, if it were properly distributed throughout the cropping season, to make agriculture quite certain without the aid of irrigation. During the last few years there seems to have been a slight falling off of the average amount of rainfall in June and July, which, with the hot southerly winds that frequently occur during these months, have made it necessary to bridge over a short interval by substituting irrigation wherever it is possible. It is the general opinion of the people in this belt of country that the hot and dry winds had more to do with the shortage and loss of crops in the season of 1890 than the lack of rainfall. Farther west the failure of crops seems to be due more to a scanty rainfall throughout the whole year.

There are evidences which have come to our knowledge, both from statements of old settlers and from study of the climatic conditions, that must have existed before the settlement of the country, which lead to the belief that there is a recurrence of wet and dry periods which have extended over the country under consideration. We have not been able to fix the probable return of these periods, but they seem to follow each other quite regularly, with intervals of 11 to 14 years. That the past few droughty years were not the dryest that were ever known is proved by the fact that in some of the small lakes on the plains, which were dried up during 1890, old buffalo trails are found in the bottom of these then dry lakes, leading to the very lowest point where water could be obtained. The drying up of other lakes that year shows small dead trees and brush that were once growing in what has been a lake for many years. The distinct traces of stages of hig and low water in thousands of lakes in this country marks the occurrence of both wetter and dryer periods than have existed within the past few years. Many of these beach lines are below the present surface of these lakes, but the majority of them are above, and the conclusions to be drawn from these indications are that the few past years mark the average end of the cycle of dry years.

It has been the observation of these people who have lived in the country for some time that the rain does not fall in such torrents as formerly; also that dews on the grass in the morning are seen more frequently than ten or fifteen years ago. New springs of water are showing in many place, and some of the old ones are increasing in their volume; in fact there are many signs which indicate that the climate is undergoing a gradual change, and that the country is being better fitted for the occupation of man; but the great drawback is the liability of a return of the cycles of dry seasons, when a few weeks during the cropping season must be bridged over by irrigation, or be followed by a failure of crops more or less disastrous. It is also observed that the prairie grasses found in the more humid sections of the Great Plains are gradually occupying the country to the west, which was formerly covered by gramma and buffalo grasses. The latter named grasses seem to occupy and mark the country, which is at present doubtful to occupy for agricultural purposes without the substitution of irrigation. On our trip along the hundredth meridian through the State of Kansas we found the gramma and buffalo grasses occupying nearly the whole country, with here and there little patches of the central Kansas grasses growing. These have come within the last few years.

Judging from the past history of the westward movement of the limit where agriculture can be safely carried on, on the great western plains in Kansas and Nebraska, we can safely anticipate that with the occupation and tillage of the country along its front, the line will slowly advance, but slower as it moves westward to higher altitudes and toward a country that will always require irrigation.